J.E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

TWO XIX CENTURY GERMAN CATALOGUES OF MINERAL COLLECTIONS IN THE MUSEU DE HISTORIA NATURAL OF THE UNIVERSIDADE DE COIMBRA (PORTUGAL)

Manuel S. Pinto[1], Pedro Callapez[2] and Claudia Schweizer[3]

[1]GeoBioTec, Universidade de Aveiro, 3810-193 Aveiro, Portugal. mspinto@ua.pt
[2]Departamento de Ciências da Terra, Universidade de Coimbra, 3000-272 Coimbra, Portugal. zepallac@gmail.com
[3]Am Modenapark 13/11, A-10130 Vienna, Austria. c.schweizer@gmx.at

Abstract. In the rare books and manuscripts section of the library of the Department of Earth Sciences of the University of Coimbra, two handwritten (in German) catalogues are kept that refer to a total of some 1,900 numbered specimens of minerals and rocks. They were acquired for the Museum of Natural History most probably around 1847 from Paulino de Nola Oliveira e Sousa (1759-1831) who had used them in teaching metallurgy at Coimbra and must be the author of the catalogues. These catalogues express some of Werner's views on systematics of minerals and rocks and to a small extent on geognosy, and so they are precious documents for a better understanding of the history of the geological sciences in Portugal. Contrary to several other catalogues of the Museum, the German catalogues do not show any influence of the French school of mineralogy.

1. INTRODUCTION

In the rare books and manuscripts section of the library of the Department of Earth Sciences *(Departamento de Ciências da Terra)* of the University of Coimbra, two handwritten (in German) catalogues are kept that refer to a total of some 1,900 numbered specimens of minerals and rocks. Such documents deserve more attention than they have received so far, not only because they describe a relatively large number of specimens, but also because they present classifications of minerals and rocks according to A. G. Werner's (1749-1817) concepts, so being of interest from the point of view of the history of geological sciences in Portugal. Also some questions have been raised about the possible authorship of the catalogues, about the use that was made of them and about the origin of the collections and how and when they reached the University of Coimbra (see, for instance, Monte-São, 1872 and Portugal Ferreira, 1998).

This paper is an attempt to give some answers to such questions as well as to describe very briefly the contents of the catalogues. For that effect it is necessary to present a few aspects of the history of the Faculty of Philosophy *(Faculdade de Filosofia)* of the University of Coimbra, of its course in Philosophy and of the University's Museum of Natural History *(Museu de História Natural MHN)*.

2. THE MINERAL AND ROCK COLLECTIONS AND THE CATALOGUES OF THE MHN (1772-1902) – A BRIEF SUMMARY

The MHN was founded in 1772, when the university was reformed by the Marquis of Pombal (1699-1782), prime minister to King Joseph I (1714-1777), and a Faculty of (Natural) Philosophy was also created. A four year course in Natural Philosophy began to be taught in the Faculty using for practical classroom demonstrations collections of "natural objects" that were kept in the Museum. The collections were catalogued according to scientific criteria found in textbooks written by well-known authors (Portugal Ferreira, 1990; 1992; 1998; Batista, 2000).

The use of the Museum's mineral and rock collections from 1772 up to the beginning of the XX century was successively made in demonstrations during lectures on Natural History (1772-1791), Zoology and Mineralogy (1791-1835), Metallurgy (1801-1835), Mineralogy, Geognosy and Metallurgy (1835-1844), Mineralogy, Geology and Mining (1844-1885) and Mineralogy and Petrology (1885-1902). The names of these courses subjects were adopted when changes were introduced in the syllabuses of the Faculty as in 1791, 1835, 1844 and 1885, or when small changes were implemented, as in 1801, when Metallurgy (taught until then in Chemistry) became an independent course endowed with a specific laboratory; this laboratory was incorporated in the Museum around 1836 (Portugal Ferreira, 1998).

The Museum received its first collections from Domingos Vandelli (1730-1816), professor of Chemistry and of Natural History at the University, and from T. R. van Deck, a private collector. From then on it followed for many years a policy of buying, of encouraging donations and of receiving specimens collected by naturalists in Portugal and in its colonies. Around 1806 the Museum received a set of specimens from the Royal Ajuda Museum, in Lisbon, which was headed by Vandelli. According to Portugal Ferreira, around 1847, the Museum may have received a collection that had belonged to Paulino de Nola Oliveira e Sousa (1759-1831) after the Faculty had decided to acquire it, as shown in the minutes of one of its meetings. The Brazilian-born Sousa, a Discalced Carmelite monk, had been a member of the teaching staff of the University known to possess an excellent private mineral collection (Ferreira, 1998).

As for catalogues, and apart from the list of specimens received by the MNH from the Ajuda Museum, the following are known (Portugal Ferreira, 1998; Pinto & Marques, 1999): a) *Mineralogia - 1ª Sala* (1st room), dated around 1822, a manuscript referring to 1,300 specimens (the Ajuda ones included) of minerals and rocks prepared by E. J. Barjona (1760-1831), who followed Brochand's and Haüy's (1802-1822) ideas on systematics; b) *Catálogo mineralógico - 1ª Sala*, a manuscript dated around 1826, referring to 1,784 specimens (including the previous ones), prepared by C. R. Macedo (1790-1831); c) *Catálogo dos Produtos Mineralógicos de Portugal*, dated 1829, prepared by J. J. Barbosa (1792-1855), which had some more samples than the previous ones and in which a reference was made to rocks and incrustations kept in the *2ª sala* (2rd room); d) *Catálogo da Colecção Mineralógica do Gabinete de Geognosia da Universidade de Coimbra* (manuscript), which is a translation, made in 1836 in Coimbra by H. C. Rivara (1809-1879), of a German catalogue of minerals and rocks classified according to Werner's concepts (see below); e) *Catálogo da Colecção Mineralógica do Museu da Universidade de Coimbra*, dated 1850, prepared by H. C. d'Almeida e J. M. d'Abreu (1818-1871), who followed O. P. B. Dufrénoy's (1792-1857) ideas on classification. According to Julio Henriques (1838-1928), this catalogue included the 1902 specimens mentioned in Catalogue d) above – 1574 described in the first part *(Mineralogie)* and 328 in the second part *(Geognosie)* – that the MHN had received from Germany (forming the so-called German collections) in a date that he does not indicate (Henriques, 1875). So the depreciative comments made in 1872 by the Visconde de Monte-São, the professor in charge of the section of mineralogy of the MHN, about the state of collections have no apparent reason (Monte-São, 1872). Curiously Portugal Ferreira writes that the 1850 Catalogue did not include rocks and listed 1987 specimens (Portugal Ferreira, 1998).

So four catalogues originally in Portuguese of the collections of the MHN were prepared that showed the influence of the French school of mineralogy on systematics of minerals. Possibly they were prepared just to follow recommendations made at different times by the *Congregação* (Congregation) of the Faculty of Philosophy. Portugal Ferreira (Ferreira, 1992) points out that the French school was dominant in the XIX century in Coimbra, not only in teaching aspects, but also in the organization of the MHN.

Before that Werner's ideas had reached Portugal also through his former Portuguese and Brazilian-born students – J. B. Andrade e Silva (1763-1838) and others – who had studied under him in Freiberg, in the late 1700s. But Andrada e Silva, who became full professor of Metallurgy in 1801, was never involved in the preparation of catalogues.

Paulino de Nola O. Sousa and João António Monteiro (1769-1834), the latter also a member of the teaching staff of Coimbra University, who, supported by allowances paid by the University, went to Paris in 1804 and stayed for six years in Freiberg, from 1815 onwards, certainly were influenced by Werner's ideas (Ferreira, 1998). While Monteiro never returned to Portugal, Sousa came back, in 1821, and most probably it was him who took the German catalogues to Coimbra.

3. THE GERMAN CATALOGUES AND COLLECTIONS

One of the German catalogues kept in the rare books and manuscripts section of the library of the Department of Earth Sciences is a soft-cover volume of 116 pages, 20.5Í32.8 cm each, not numbered, with the title *Verzeichnis zu einer aus 597 Nummern bestehenden orÿktognostischen Mineralien Sammlung, gefertiget im Monat Januar 1818* (Catalogue of an oryctognostic mineral collection, consisting of 597 numbers, edited in January 1818). The text has two parts, the first one listing some 597 numbered specimens and the second one, a supplement, adding new sample numbers and more information about many of the 597 numbered specimens. The original numbers of the specimens, in black, had been replaced in both parts by different numbers in sepia and numerous corrections and additions had been made to the text, also in sepia, in both parts. The black and sepia handwritings seem to belong to the same person.

The other catalogue is a hardcover book of 142 numbered pages, 16.5 Í 20.8 cm each, with no title in German, but showing on the front page (handwriting different from the text) and on the spine (printed) "Catalogo Allemão Mineralogia e Geognosia". On the spine is also printed the word "MUSEU" meaning that the book belonged to the library of the MHN. The catalogue has two parts, the first one *(Mineralogie)* comprising a list of minerals and some rocks, numbered 1 to 1574, presented in the hierarchic order of classes, families, genera, species and varieties arranged according to Werner's systematics. The minerals' description follows their characteristics as elaborated also by Werner. Most mineral species are represented by various samples (varieties), differing in colour, crystal characteristics and the localities of their occurrence. The classes are four, the first and the fourth ones, "Earths and earthy minerals" (ca. 60% of the specimens) and "Metallic minerals" (ca. 38% of the specimens), respectively, comprising the larger number of specimens.

The second part of the catalogue *(Geognosie)* is split up into two sections with the titles *Samlung zur Darstellung der Structuren der Gebirgsgesteine* ("Collection to illustrate the structures of mountain rocks", describing the structures of rock formations as shown by 47 numbered samples), and *Aufstellung der Gebirgsgesteine in systematischer Ordnung, wie solche der zweite oder angewandte Theil der Geognosie vortraegt* ("Presentation of mountain rocks in systematic order, as it is documented by the second or applied part of geognosy", describing rocks in systematic order). That points to the fact that such collection served to document in a practical way the lectures on geognosy. Like the mineralogical collection, the rock collection follows the classification set up by Werner. Likewise the samples are continuously numbered (1 to 47 and 48 to 328) throughout the catalogue, several samples representing the same rock type and its varieties. It is clear that the description of the samples is based on and differentiated by their mineral content.

Specimens of rocks and minerals from all over the world make up the collections, notably from Germany and particularly from the Freiberg area.

Both catalogues have exactly the same introduction (*Einleitung*) in which a reference is made to Christian A. S. Hoffmann's (1760-1813) *Handbuch der Mineralogie* (1811), continued by August Breithaupt (1791-1873) with three further volumes (1812–1818). The handwriting is the same in both catalogues. In fact, what the author of the second, hardcover catalogue did was: a) renumbering all the specimens in the soft-cover catalogue and making corrections and additions in sepia (text of mineralogy of the hardcover book listing 1574 numbered specimens), and b) adding the information about the rocks listing 328 specimens (text on geognosy).

As the soft-cover catalogue was written in January 1818, the hardcover catalogue (that practically incorporated it) is more recent than that dated 1818. On the other hand 1836, date of the translation of this catalogue made by Rivara, is the latest date possible for its preparation. Rivara, who let the reader know that he had felt difficulties in translating the catalogue, does not make any mention on the date of the catalogue, certainly because he could not find any in it.

Who prepared the catalogues? Most probably Paulino de Nola Oliveira e Sousa, since: 1) he owned the collections described in the catalogues until he died; 2) he had received the influence of Werner's ideas when being in Freiberg; 3) he certainly had a good command of German after living for about six years in Germany; 4) he had the chance of looking for specimens during his travels in Europe; 5) he needed to have a collection at hand in Coimbra to be used in his teaching of metallurgy, which he carried out from 1823 to about 1831.

The soft-cover catalogue was ready in 1818, that is three years after Sousa's move to Freiberg. The hardcover catalogue was probably prepared here before his return to Coimbra. João A. Monteiro may have helped him: the catalogues show a handwriting that has more similarities with Monteiro's than with Sousa's.

Sousa most probably brought the collection with him by ship since there is no indication that it was dispatched by sea, contrary to what happened with books and instruments that he conveyed to Coimbra.

In Coimbra, the collections and the catalogues must have been kept in the laboratory of metallurgy at least until Sousa's death in 1831. In 1835, the chair of Mineralogy, Geognosy and Metallurgy was created, and this was followed by the incorporation of that laboratory into the MHN by decision of Professor Roque J. Fernandes Thomaz (1808-1871) (Ferreira, 1998). In 1836, Rivara translated the hardcover catalogue; around 1847, Nola's collections were acquired for the MHN, and in 1850 they were classified according to Dufrénoy's ideas. A pencil note written in 1880 on p. 328 of the hardcover catalogue let us know that 11 samples (less than 1%) were missing (mostly minerals) which gives some evidence that the collections had been well kept for some 60 years.

4. CONCLUDING REMARKS

Werner's concepts on the systematics of minerals and rocks, as expressed in the German catalogues, were not used in the preparation of the other MHN catalogues. The works of his followers, Christian Hoffmann and August Breithaupt, were not able to compete for that purpose with the ones authored by Brochand, Haüy and Dufrénoy. In fact, even the influence of the French school of mineralogy in the organization of the MHN was over in 1878 when Dana's systematics was used for that effect by Gonsalves Guimarães (1850-1919) the professor appointed to the chair of Mineralogy in that year (Portugal Ferreira, 1998).

Werner's concepts on geognosy as shown in the hardcover catalogue (for instance when primitive, transition and other rocks are mentioned) lost gradually their influence, and the catalogue could eventually serve for teaching purposes, neither.

The German collections, with their 1,900 specimens from all over the world, certainly helped the MHN to become one of the richest in Portugal in the XIX century, if not the richest. And certainly they have been used for the good purpose of teaching generation after generation of students in classroom demonstrations.

The respective catalogues enriched the library of the Museum of Natural History, and they are precious documents for a better understanding of the history of the geological sciences in Portugal.

REFERENCES

Batista, M.T. 2000 Gabinete de História Natural. In: Carreira, I., Reis, J.A., Batista, M.Y. and Ribeiro, R. (eds.), O *Gabinete de História Natural / Revivências*. Museu de História Natural, Fac. Ciências e Tecnologia, Univiversidade Coimbra, Coimbra, 9-17.

Henriques, J.A. 1875. *Considerações sobre o Folheto Intitulado Resposta do Visconde de Montesão*. Imprensa da Universidade, Coimbra, 40 pp.

Monte-São Visconde de 1872. *Relatório sobre a Secção Mineralógica do Museu de História Natural*. In: Carvalho, J.S. (ed.), *Memória Histórica da Faculdade de Filosofia*. Imprensa da Universidade Coimbra, 215-233.

Pinto, J.M.S. and Marques, J.F. 1999. *Catálogo da Galeria de Minerais José Bonifácio d'Andrada e Silva*. Museu Mineralógico e Geológico-Museu de História Natural, Fac. Ciências e Tecnologia, Univ. Coimbra, Coimbra, 137 pp.

Portugal Ferreira, M.R., 1990. O Museu de História Natural da Universidade de Coimbra (Secção de Mineralogia e Geologia) desde a Reforma Pombalina até à República. *Memórias e Notícias do Museu Laboratorio Mineralogico e Geologico Universidade Coimbra*, 110, 53-76.

Portugal Ferreira, M.R. 1992. Pioneiros da Mineralogia em Portugal. *Revista Colóquio/ Ciências*, 10 (5), 79-98

Portugal Ferreira, M.R. 1998. *200 Anos de Mineralogia e Arte de Minas: desde a Faculdade de Filosofia (1772) até à Faculdade de Ciências e Tecnologia*. Fac. Ciências e Tecnologia, Universidade Coimbra. Coimbra, 188 pp.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

COAL EXPLOITATION ALONG THE LENA RIVER (PORTUGAL): A SIGNIFICANT IMPACT ON THE REGION'S ECONOMY (1854-1956)

José M. Brandão[1] and Herlander E. Silva[2]

[1] LNEG-IP/Centro de Estudos de História e Filosofia da Ciência, Univ. de Évora.
Est. da Portela, Zambujal, Alfragide, 2720-866 Amadora, Portugal.
josembrandao@gmail.com
[2] Researcher of local History. herlandersilva@gmail.com

Abstract. The existence of coal deposits in the Lena valley has been known since the late 18th century. However, it was not until the second half of the 19th century that systematic search and exploitation began, albeit in an intermittent fashion and with no economic impact until the middle of the First World War. The foundation of *Sociedade Mineira do Lena* (Lena's Mining Enterprise) in the early 1920's, which included the majority of the concessions owned by various entities, was the starting point of an important period of regional industrialization based on mining activity. Despite all its difficulties it worked, until mid 1950's, in partnership with other high economic and social impact industries in the district of Leiria. The uniqueness of Lena's coal industry, in the overall picture of the coal national industry, stems from the fact that the most important concession owners invested in other business areas, such as the construction and exploration of a mine railway line open to the public, and the production and distribution of electricity, concomitantly with the mining activity. Although these businesses aimed to boost coal exploitation, they became an impediment to the development of mining activity, which was already debilitated by the poor quality of the lignite and by marketing difficulties. This work provides a chronological summary of some of the high moments of life at the mining camp in an attempt to counter the apparent weakening of the collective memory towards this important industry.

1. SURVEY AND EXPLOITATION

The coal deposits of the Lena River valley, which spread mainly over the counties of *Porto de Mós* and *Batalha* (district of *Leiria*), display layers of lignite of medium quality and variable strength, interstratified with limestone and marls dating from the Middle and Upper Jurassic. The oldest records of mining activity refer to jet mining at *Hortas* during mid 1740's (Ackermann, 1908); however, a systematic survey of the region's potential for collieries and mining of iron, labelled as *"agents of modern civilization"*, did not take place until the second half of the nineteenth century, under the plan of industrial development spurred by the Liberal government.

Carlos Ribeiro (1813-1882), an engineer of the State Mining Department, carried out the first geological studies in the Lena valley and in other mining regions of the country. The studies name the main coal deposits and some scattered occurrences of iron oxides, some of which were eventually exploited (Ribeiro, 1857; 1858).

Jorge Croft (1808-1874), an English merchant residing in Portugal, was one of the first people to register *"minas de carvão e ferro"* (coal and iron mines) in the municipality services of *Batalha* and *Porto de Mós* in

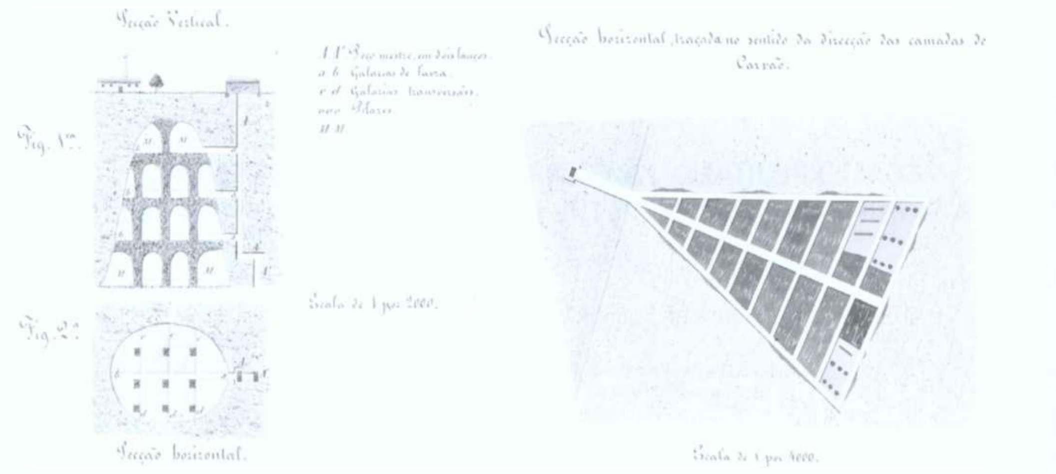


Figure 1. Illustration of the mining plan for the mine of *Porto de Mós,* as proposed by J. Pezerat (1860). AHM-DGGE.

1854. The several experts he invited to study the occurrences fuelled expectations of a promising region (see Relatorios dos engenheiros, 1863), in agreement with Carlos Ribeiro, who estimated that some deposits had the potential to yield production for over 500 years (Ribeiro, 1857). It should be noted that C. Ribeiro based his statements on surface observations only, a fact exacerbated by the lack of adequate mapping. However, the author safeguarded himself by asserting the need for thorough surveys. The expectations covered the quality of coals that, according to studies performed at the official laboratory of *"Casa da Moeda"* in Lisbon, had shown *"a power similar to Newcastle coal"* (letter from J. Norton in Ribeiro, 1857).

A promising future appeared to be in store for the region. However, the poor quality of lignite and the shortage of transport to ensure a fast delivery to the market at competitive prices, soon turned out to be serious obstacles to the development of the extraction industry, which only had a significant impact during the World Wars, due to difficulties related to the importation of coal from England.

Although the layers of lignite outcrop at places, its industrial exploitation was entirely done underground via a system of wells, which were vertical or inclined according to the slope of the strata, and galleries under the direction of the coal layers.

The mining methods used were invariably the longwall, which had better resource recovery (Andrade, 1928). Whenever this method was not appropriate due to the nature of the mine's roof, as in the *Batalha* mines for instance, the mining was performed using the room and pillar method (Fig. 1). Recovery of coal pillars was made prior to retreating from the rooms. Underground and surface transport was made in mine cars with a capacity of 600 to 800 Kg, running on a *Decauville* track—the vans were pushed manually or pulled by animals. The first attempts at mechanical extraction were made during the First World War, when it was necessary to intensify mining; however, more significant investments were made only in the 1920's, with the introduction of electrical and compressed air equipment. A similar effort was made during the Second World War, when the region experienced a period of greater mining activity.

Irregularity in consumption, which was always subject to coal quality, and the policies of successive managements in the mining region, determined the rhythm of production.

The overall production of the Lena mines seldom exceeded 10, 000 tons a year, until the power station in

Porto de Mós went into operation in the early thirties, increasing its production significantly afterwards and trebling it during World War II, when it reached approximately 40, 000 tons in 1945. Production plummeted in the late forties due to structural problems, and ceased completely in mid 1955.

This state of affairs impacted on the number of staff employed as technical and administration personnel and as labourers. Despite the fluctuations, the various concession owners kept an annual average of over one hundred workers between 1920 and 1940, most of which were men working underground and some women and boys employed in sorting out the coal.

2. A STRATEGIC VISION

2.1 Lena's Mining Enterprise and the emergence of the "Couto Mineiro"

At the time of the First World War, the mining activities at Lena had come to a standstill due to the lack of capital and investors. This situation came to the attention of official authorities, which regretted the fact that "intensive mining" had not yet been implemented in Portuguese mines, namely at the Lena's valley (*Pego,* 1916). As a reaction to the high price of coal and wood, which had reached outrageous values, exploitation of the best deposits was resumed, namely at *Alcanadas, Chão Preto* and *Ferraria*, and at the south end of the mining area in *Cabeço do Veado* and *Valverde*.

By the end of the Great War coal was still in short supply and had reached prohibitive prices due to the lack of transportation; this led the Government to enact a number of aid measures for concession owners, in order to encourage mining and improve coal transportation (see Decreto nº 4801 dated September 13th, 1918). The legal framework thus created might have helped the emergence of *Sociedade Mineira do Lena Lda.* (SML) (Lena Mining Enterprise), founded in 1921 by the majority of the concession owners still in business, in an attempt to put together some capital and place the region firmly in the context of national coal producers. This association probably resulted in the foundation of *"Couto Mineiro do Lena"*, recognized by Order of March 27th, 1925, that covered an area of 8, 000 hectares and a total of 44 concessions (not all concessions amounted to actual work, so many of them marked as a guarantee of the possibility of further exploration in depth, or as a strategic reserve).

The foundation of SML brought about a new strategic vision and it is fair to say that it was the starting point of a period of progressive re-equipment and mechanization of production. The technical direction of the mines was given to the Count of Arrochela (1884-1963) and to Carlos Freire de Andrade (1893-1956), renowned mining engineers.

SML also invested in the improvement of transportation with the construction of a narrow gauge railway extension linking the mines of *Batalha* to the *Linha do Oeste* one (national railway network), hence providing an alternative to a route of more than 20 Km over roads in disrepair (this extension of 13 Km, referred to as "Martingança Minas", replaced the line built in 1917 by special permission from the Government in order to work on the deposits of Batalha). The intersection of the lines was established at *Martingança*, facilitating the supply to the cement factory at *Maceira*, which had come into full operation in 1923 and consumed coals from the Lena mines.

In the meantime, activity was increasing in the mines of *Bezerra* and *Vale de Bragadas*, which had been discovered in 1920 and produced what turned out to be the highest quality coal in the region (the mines of *Bezerra* were, until the early thirties, the only major source of revenue of the concessionary that focused on improving living and working conditions of staff). However, its localization at the top of the *Pevide*

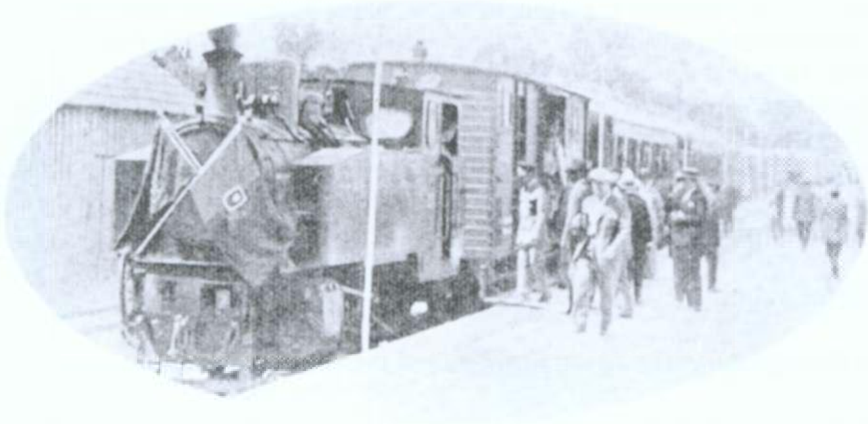


Figure 2. The narrow gauge railway at the *Pinheiros-Calvaria* train station in September 9th, 1930, by courtesy of the APAC (Portuguese Association of the Railway Friends).

mountain meant that the transport of coal to the railway line, made by ox-carts or mules, was difficult and time consuming.

In order to solve the transportation problem, SML negotiated with the state railway company the construction of a line dedicated to the mining works that connected, along 15 Km through the mountains, the village of *Batalha* to the *Alcanada* mines and to the *Bezerra* mines via *Porto de Mós* (Fig. 2).

In spite of expressing some doubts about the feasibility of the venture, the state ended up praising SML for building the line instead of opting for an aerial tram, a more obvious solution given the region's topography.

2.2 The times of "The Match Company"

The need to obtain additional capital to invest in the mining camp may have been determinant for the transfer of assets from the deficient SML to a new company formed in 1924, *The Match and Tobacco Timber Supply Company SARL.*, which had investments in the matches, tobacco and wood markets.

Match, as the company will be referred to henceforth, was the starting point of what probably was to be the most promising period in the existence of *Couto Mineiro.* As examples of the above are the attempt to launch a program of high coal recovery rate (which did not go ahead), the extension of the railway system, and the construction of a power station that used regionally produced coal with lower demand.

Match's varied range of enterprises required the allocation of large sums of money that the company raised with offers of shares in the Lisbon and Paris stock exchanges, thus building a capital of 750, 000 pounds in 1927. Only a third was reserved for the mines exploitation (see Request of the Match dated from August 23rd, 1929; AHM-DGGE).

2.2.1 Lena's mining railway

Considering the possibility of increasing the coal supply and expanding the railway line for other uses, within the bounds of the law on mining transportation (see Dec.-Lei nº 11 852, D. Gov. 144, 1ª s., July 6th, 1926), *Match* went ahead with the alteration of the gauge line from 0.60 m to 1 meter in the *Batalha* to *Martingança* line, and also with the construction of a section to the mines of Bezerra (24 Km). The main station was situated in *Porto de Mós*, where a power plant, workshops, stables of rolling stock, and staff accommodation were built.

In January 1927 the Government issued a permit that allowed *Match* to exploit the transportation of goods and passengers, in a joint service with the national railway (Western Line) (see "Aviso ao Público nº 57", Anexo 122 à Gazeta dos Caminhos de Ferro, December 24th, 1926). The time was ripe for *Caminho de Ferro Mineiro do Lena* (Lena Mining Railway), still fresh in the memory of those who knew it.

However, the construction of the lines and the purchase of material forced the company to request a significant bank loan, guaranteed by the State, through the mortgaging of its assets and expected income (Dec. nº 13.083, D. Gov. nº 128. of June 21st, 1927), which would seriously jeopardize the company's future (The first trouble in meeting the financial commitments started the following year as the train business was much lower than expected (see Relatório da *Match*, exercício de 1928; AHM-DGGE).

The train arrived at Porto de Mós towards the end of 1928 and to the mines two years later.

Although the railway line was socially and economically very important to the region, the investment caused some apprehension to the authorities that supervised the mining activities as the money lent by the State, to improve the works at *Couto Mineiro,* was being channelled for the railway in detriment of mine works. There was a real risk that no amount of extraction would justify the investment.

Such state of affairs was certainly decisive to bring *Match*'s project of crossing the *Aire* mountain to the east with a new 60 Km line, that would connect the mines to Northern Line (national network) at the station of *Entroncamento,* to a stop. The new line was meant to provide a faster hauling for coal and a new public service.

2.2.2 The "Central Lena" (Porto de Mós power plant)

The construction of a power plant for burning coals from *Batalha* at the mouth of the mine was one of *Match*'s projects; this solution had already been proposed by previous concessionaries when it became clear that the coal was not acceptable for marketing purposes, due to the high content of sulphur and the resulting ashes. A power plant would allow the company to make the exploitation of the mines feasible and to expand in the area of production and distribution of electricity (Fig. 3). Furthermore, low cost energy would allow the full development of the mining works in the southern end of the mining camp, where the coal seemed to be of higher quality, which was not confirmed later.

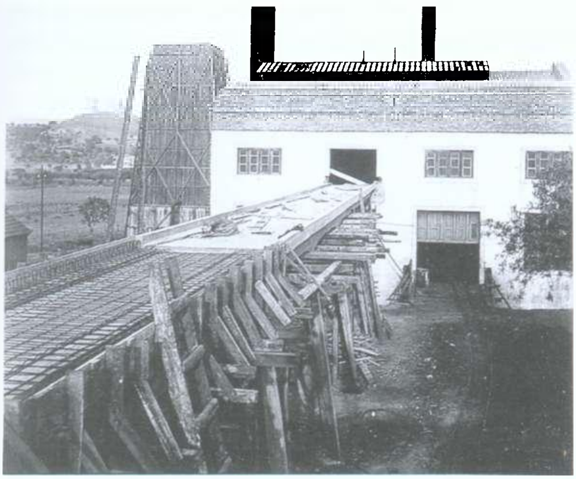


Figure 3. New constructions at the *Central Lena* in Porto de Mós, 1938. H. Silva's private collection.

The availability of an appropriate water supply determined the construction of the power plant, with an initial power of 1, 000 KW, at *Porto de Mós*, although it made the production more costly as it involved the transportation of the coal from the *Alcanadas* (see Relatório da *Match* exercício de 1928; another railway line to Barrojeiras was built at a later date, as Barrojeiras became the main export destination for the Alcanadas mines, AHM-

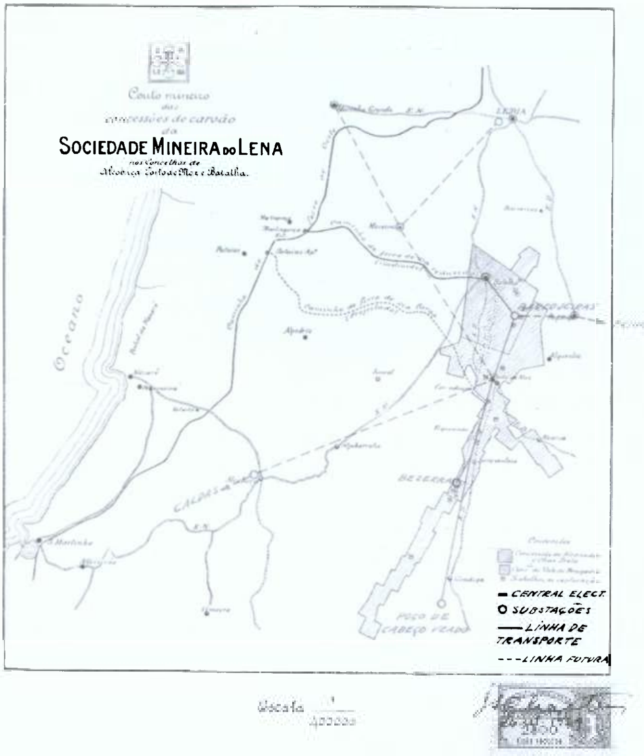


Figure 4. Main high voltage power lines built by *Match*. AHM-DGGE.

DGGE) mines in a dedicated extension of the railway which was not completed until 1940.

The company's expectations were high when, in October 1930, it was granted, in the name of the public interest, the concession to supply electricity to the counties of *Leiria, Batalha, Marinha Grande, Porto de Mós* and *Alcobaça* (it should be noted that *Match* may have benefitted from the favorable disposition towards the development of regional electrification projects spurred by the development policy of minister Ferreira Dias). If the concession meant a victory for the company, it also aggravated its liabilities due to the costs of building the high voltage private network (Fig. 4).

The Lena power plant became fully operational in 1932 with a transmission line and power distribution for the mining works and another for the public service that supplied important industrial customers, such as the weaving factory of *Alcobaça* and the cement factory of *Maceira-Liz*. It also allowed the installation of the first municipal public lighting networks.

3. DEGRADATION OF THE ECONOMIC SITUATION

The lack of manpower, the level of indebtedness and losses with businesses outside the mining area forced *Match* to undergo a profound transformation, reducing its share capital and assuming a new legal designation: *Empresa Mineira do Lena SARL.* (EML), maintaining only the extraction activities, the train and the power plant.

The Government, the main creditor, had the power to appoint a member of the board who, from then on, followed the company's management closely, mediating all decision-making concerning the life of *Couto Mineiro*.

The thirties were a decade of serious economic difficulties for the company, which nearly paralyzed the activity in *Couto Mineiro* twice, including the railroad and the power plant activities. The period between 1932 and 1935 was probably the most difficult one due to a combination of highly unfavorable circumstances: the termination of coal purchases by the *Companhia dos Caminhos de Ferro* (national railway company), which claimed that those purchases were not suited to their locomotives (Extract from the 1930 minutes of C.P.'s Administration Board, of January 30th, 1931; C.P. historical archives); the sales decline to the hydraulic lime factory of *Maceira*, and the end of the electricity supply to the cement industry. This state of affairs led to the recapitalization of the company and the suspension of payment of wages, a situation with severe social consequences throughout the region.

To address these problems, which resulted in part from the international and national crisis, the company was forced to suspend unprofitable passenger services (the suspension of the railway service of the Mineira do Lena was not definitive, as the company continued to ship coal, although not regularly; two years later, it opened new freight services, which in fact, it kept providing them, although on an individual and private basis; the trains circulated until the late forties and only stopped being a part of the national railway network in 1950-see Decree-Law no. 37 822 of 16th of May) and to sell part of its rail network, requesting further state aid.

The prospect of depletion of the mines of Bezerra, which turned into a reality in the late thirties, and the need to find alternatives, justified the drilling campaign which was conducted with urgency in the mines of *Ferraria, Valverde, Batalha* and *Vale Grande* between 1937 and 1941. The survey only showed a reserve of approximately 2,000,000 tons of lignite in *Batalha*, *"consistent with its role of supplying the power plant of Porto de Mós"* (Vianna, 1943), partially explored with the development of works on the 5th level, in the area of *Barrojeiras*.

The increase in the production supplied to the power plant and to other consumers during the years of World War II allowed the company to achieve a certain financial stability, although precarious, compromised by the sale of the power plant and its distribution network in 1948.

The agreement for the sale and concession to the *Sociedade Eléctrica do Oeste Lda.* (SEOL) (Western Power Company) determined that the new owner would continue to consume the coals of Lena, on an average rate of 700 tons a month. However, the consumption levels became less consistent and started to fall sharply towards the end of the decade, when consumption practically ceased, since the plant was only operational when there was lack of rain and, consequently, lower production at the hydro-electric plants occurred.

EML urged the State to enforce the contractual obligations and the law in force, which required the purchase and consumption of Portuguese coal; however, the development of new national hydro-electric plants, represented in the SEOL share capital, ended up derailing the project, condemning the mines inexorably (the contract between the EML and SEOL provided that the latter would pay compensation to EML in case it did not use the coals. However, it was rapidly understood that without the power plant in operation, there would be no alternative buyers for coal and therefore it would not be realistic to keep the mine in activity).

Profoundly recapitalized and no longer benefiting from the possibility of being awarded further state aid, EML was legally dissolved in August 1953, and *Couto Mineiro* was dissolved by the Government Ordinance of December 14th, 1954.

Conceição Monteiro (1902-1989), director of *Couto Mineiro* for a number of years, had tried to maintain the mining activity by creating the *Sociedade Carbonífera de Porto de Mós Lda.*, the ultimate concession holder of some of the Lena mines (See list of mines requested and excluded in the D. Gov. no. 294, III s. of December 17th, 1954). However, few works were performed until its abandonment in mid 1956.

4. FINAL NOTES

The decline of the Lena's mining camp was, to some extent, a reflection of the general crisis affecting all lignite mines in the center of the country, which were abandoned one after another, as a result of the poor characteristics of the coals.

In the case of the Lena mines, one could also add that there was an excessive optimism about the future of a series of small deposits, which were hardly-known and overstated, and also a number of unfortunate management decisions. However, the history of the coals of Lena was also the result of many other realities that, for almost a century, marked the economic and social life of the region.

The opening of the mines, which brought hundreds of workers to the region; the opening of the railway line to the public service; the *Porto de Mós* power station, and the construction of the high voltage transmission network which allowed electricity to be brought, for the first time, to municipalities in the region, were, without a doubt, some of the greatest marks of regional progress.

Having left no great material evidence besides small groups of buildings, mining installations ruins and some traces of the passage of old railway lines, scattered around the counties of *Batalha* and *Porto de Mós*, all quite degraded, the memory of Couto Mineiro of the Lena fades quickly. We therefore applaud all museum initiatives aimed at recovering and enhancing its memories, and at contributing to the restoration and dissemination of the history of the mining activity in the Lena basin.

REFERENCES

Ackermann, E. 1908. Sobre as minas de azeviche de Porto de Mós. *Revista de Chimica Pura e Applicada*, 45-46, 278-282.

Andrade, C.F. 1927. Contribuições para o estudo geológico da região de Vale Grande - Mendiga. *Boletim de Minas*, 1925, 18-35.

Andrade, C.F., 1928. Mina de carvão Vale Grande. *Boletim de Minas*, Jan.-Março, 21-22.

Boletim de Minas, 1914-1938. *Reports of The Board of Directors, The Match...*

Brandão, J.M. 2008. Historiografia mineira. Contribuição para o estabelecimento de uma cronologia de factos relevantes na vida das minas de lignite de Alcanadas e Chão Preto (Batalha, Portugal). In: Brandão, J.M., Calado, C., Sa Couto, F. (Eds.), *Património geológico, arqueológico e mineiro em regiões cársicas*. SEDPGYM. Batalha, 181-192.

Brandão, J.M. 2008. Caminho de Ferro Mineiro do Lena: desígnio de progresso industrial e social In: Brandão, J.M., Calado, C., Sa Couto, F. (Eds.), *Património geológico, arqueológico e mineiro em regiões cársticas*. SEDPGYM, Batalha, 193-203.

Brandão, J.M. and Almeida, J.P. 2006. Documentos para a história do caminho de ferro mineiro do Lena. In: Rábano, I. and Mata-Perelló, J. (Eds), *Patrimonio geológico y minero: su caracterización y puesta en valor.* IGME, Madrid, 179-190.

Carvões portugueses 1941. Instituto Português de Combustíveis, Lisboa, 105 pp.

Mining processes: Historical Mining Archives (AHM), General Directorate of Geology and Energy (DGGE).

Pego, M.R. 1916. Boletim de Minas, ano de 1914. Lisboa, 3-6

Relatorios dos engenheiros inspectores de minas sobre as concessões de Croft no districto de Leiria 1863. *Imprensa Nacional. Lisboa*, 1863, 70 pp.

Ribeiro, C. 1857. *Memoria sobre as minas de carvão de pedra e ferro e estabelecimentos metalurgicos no districto de Leiria.* Typ. de Joaquim Sousa Neves, Lisboa, 24 pp.

Ribeiro, C. 1858. *Memorias sobre as minas de carvão dos districtos do Porto e Coimbra e de carvão e ferro do districto de Leiria.* Academia Real das Sciencias. Lisboa, 328 pp.

Silva, H.E. 2007. O *Couto Mineiro do Lena: histórias e memórias*. Colecção Estremadura 3, CEPAE. Batalha, 93, 2

Vianna, A.Q. 1943. *Inventário das nossas reservas carboníferas*, 1936-1943, 10 pp.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

PETROLEUM IN THE SPANISH IBERIAN PENINSULA

Octavio Puche Riart, Luis F. Mazadiego Martínez and José E. Ortiz Menéndez

E.T.S. de Ingenieros de Minas, Universidad Politécnica de Madrid, Rios Rosas 21, 28003 Madrid, Spain.
octavio.puche@upm.es

Abstract. The main events of the history of petroleum in Spain are the following: 1) The mining concession of petroleum named *El Progreso* is the first one in Spain and occurred only seven years after Edwin Drake (1819-1880) drilled the first oil well in Pennsylvania. 2) The first survey of oil production in Spain, well known as the *Tejón* borehole, was conducted by the Sondeos de Huidobro Company in 1900, in Huidobro (Burgos), and reached 501 m of depth. 3) In 1964 CAMPSA and AMOSPAIN found petroleum in the Ayoluengo field (Burgos), with a borehole of 1,349 m of depth. This was the first and only petroleum field in the continental Spain in this zone. The Ayoluengo petroleum field has been active during 35 years. In this paper we will review the history of petroleum in peninsular Spain.

1. INTRODUCTION

It has been historically known the existence of several oil evidences of solid, liquid and gaseous seeps in Spain. These evidences have guided the identification of areas that are favorable for the research of petroleum deposits.

With the discovery of some oil fields in the USA (1859), the search for this substance in Spain began. Thus, Ríos (1949) established three stages: 1) 1860-1918: based on improvisation, drilling boreholes and studies made no shortage of findings; 2) 1918-1939: with the major intervention of the Geological Survey of Spain and other Government agencies in the investigation; 3) Since 1939: with an ordering of investigations and use of more effective methods and tools, which led to the discovery of the oil field of Ayoluengo in Burgos (Northern Spain) (1964).

2. HISTORICAL EVIDENCES OF PETROLEUM

Evidences of oil have been mainly observed in the Basque-Cantabrian basin, but also in the Ebro basin, the Iberian Chain flanks, Andalusia, etc. The most significant ones are described below:

According to geographer Al-Udri (1003-1085), asphalt was extracted from the bituminous slates located near Sigüenza, Guadalajara (Vallvé Bermejo, 1996), which was similar to black fish-like bitumen or naphtha. We will no longer hear about this exploitation until the nineteenth century -i.e. in 1873 a bituminous shale

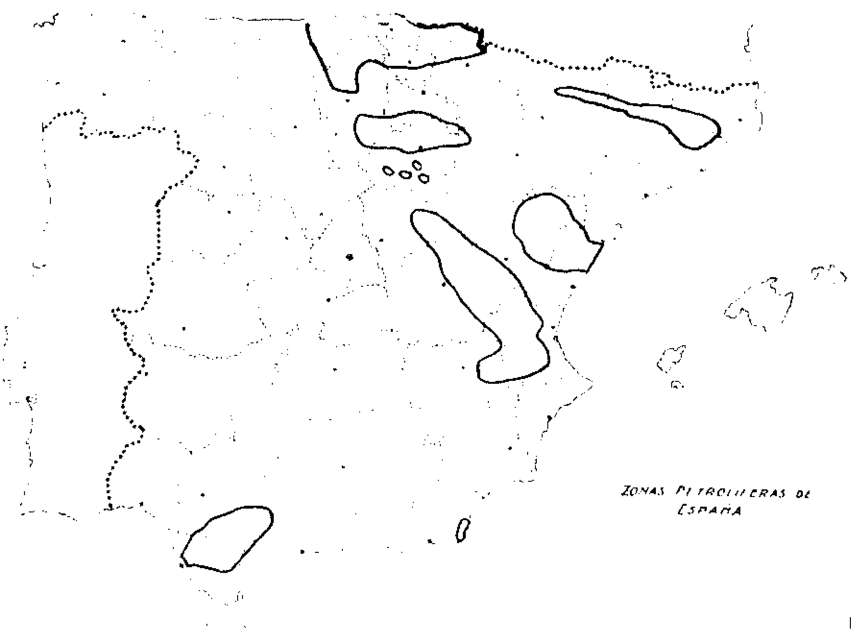


Figure 1. Map of favourable oil zones (Dupuy de Lôme, 1937).

mine called *La Fotogénica*, located south of the mill *La Raposera*, with 18 possessions, owned by Marcelino Franco, was registered (*Boletín Oficial de la Provincia de Guadalajara*, 9-V-1873). Later on, some other nearby concessions were also registered. They were called: *Por Si Acaso*, *San Adame*, *San Rafael*, *El Porvenir*, *Las Marianas*, and *Elisita*; but they had little success. In the volume of 1885 of the *Revista Minera* (p. 96) there is information about the oil mines of Sigüenza.

The Spanish Mining Statistics of 1860 (*Revista Minera*, 1862) mentioned the exploitation of asphalt from Maeztu (Álava, Northern Spain), whose extraction dates from the seventeenth and eighteenth centuries. The *San Ildefonso* mining concession was obtained in 1863. In the second half of the nineteenth century and the beginning of the twentieth century two dozens of concessions were requested in this area, emphasizing the creation of the Society of Asphalt from Maeztu in 1892. This exploitation has lasted until the present days.

Amalio Maestre e Ibáñez (1812-1872) in the "Descripción física y geológica de la provincia de Santander" (1864) noted the existence of mineral oils, previously studied by the mining engineer Cirilo Tornos (1828-1865). He was sent to Santander in 1859, where he remained until he became inspector of mines in the island of Santo Domingo in 1864. According to Maffei and Rúa de Figueroa (1872), "*In this province he noticed the abundance of bituminous slates that were completely abandoned and began the study of their use and benefit*". Also, in 1876 José González Lasala studied the bituminous oils of the Burgos and Santander Provinces (Mazarrasa and Luna, 1923).

Asphalt linked to the Wealdean sandstones of Fuentetoba (Soria), whose exploitation by underground mining began around 1850 (Dupuy de Lôme, 1937), was also recorded. When King Alfonso XIII inaugurated the Numantine Museum (1919), he received distilled gasoline for his car obtained from these bituminous sediments (*La Vanguardia Española*, 25-VII-1954). Gaya Nuño (1965) noted that the oil from Fuentetoba was also


MINAS DE PETRÓLEO EN SIGÜENZA

BREVE RESEÑA

DE

SU ESTADO ACTUAL Y DE SU PORVENIR

MADRID

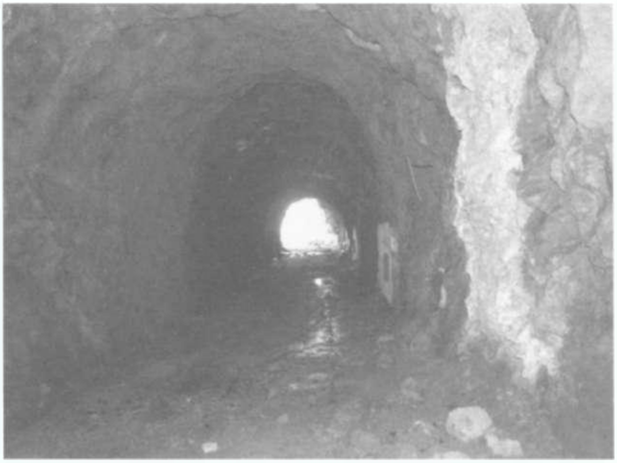


Figure 2. Book of the oil mines in Sigüenza

Figure 3. Asphalts from Maeztu (Álava, Northern Spain) in 1971.

used to illuminate the city of Soria. The Spanish government drilled a 400 m borehole between 1928 and 1929 in the PicoFrentes anticline, which cut diverse asphalt beds (Dupuy de Lome, 1937). Also, during the Second Republic, several surveys in the Sierra de Fuentes were made and 13 beds of tar sands were cut (*ABC*, 7-II-1935).

In Riutort (Barcelona) bituminous marls were exploited since 1898. French-born Jules Clavez and Philippe Petit, belonging to the Riutort Mining Company, extracted 500 tons of asphalt by means of underground mining between 1905 and 1917. Nowadays, this mine has been transformed into a museum (www.minadepetroli.com). Other oil evidences in Catalonia are those of Boixols, Abella de la Conca and Sallent de Montanisell (Lérida), San Julián de Vallfogona, Castellfullit de la Roca, San Lorenzo de la Muga, and Oix (Gerona).

In the Aragón region, the main historical evidences were located in the Bigornia Range (Zaragoza), Loarre (Huesca), and Albalate del Arzobispo, Ariño and Oliete (Teruel); in the Valencia region, Ribesalbes (Castellón) was the most important one, whereas in the Castilla-La Mancha region, the most significant evidences were observed along the whole Cuenca province, and in Barajas de Melo. In Andalucía, the main evidences appear in the Provinces of Cádiz and Sevilla (Dupuy de Lôme, 1937).

In the report of the president of the Mining Council, José María de Madariaga (1917), the oil evidences in Cádiz and Sevilla were noted by Solvay (Hevia, 2001), and also the tar sands of Fuentetoba and Cidones (Soria), the tar sands of Puerto del Escudo (Santander), the sands and bituminous limestones of Maeztu (Spain), and the discovery of oil in Barreda (Santander). Evidently, there were more evidences, but the abovementioned were the most significant ones.

3. THE FIRST CONCESSIONS AND THE FIRST BOREHOLES

The first survey of oil production in Spain (but without any economic benefit), known as the *Tejón* borehole, was conducted by the Sondeos de Huidobro Company in 1900, in Huidobro (Burgos), and reached 501 m of depth (Ayala, 2007). In the late nineteenth century a 40 m borehole was already drilled (Dupuy de Lôme, 1937).

According to the Spanish Mining Statistics in 1866 (*Revista Minera* 1868, 19, pp. 728-729), in this area

Figure 4. Oil mine of Riutort, Alto Bergadá, Barcelona.

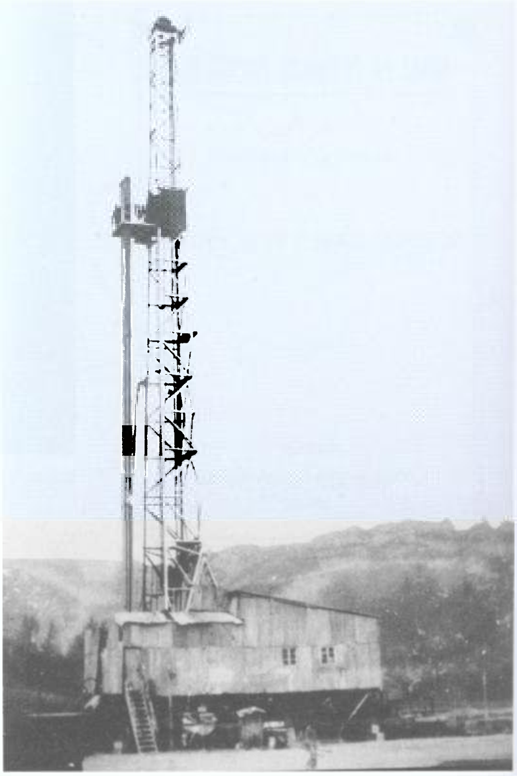


Figure 5. Zamanzas borehole (Libro conmemorativo de CAMPSA, 1928-1958).

there was something like crude oil inside the *La Borrega* mine, "*The waters that seep through the ground and run along the sandstone layers that constitute it, drag a certain amount of mineral oil*". For this reason, the mining concession called *El Progreso* began to operate. According to Pascual Madoz (1847), these copper mines were opened in the eighteenth century, and they were re-opened in 1841 by the company *La Iberia*, which named the mine *La Borrega*. In 1858 two other mines related to the same substance were opened, under the names of *Aristóteles* y *Convertida*. The concession of *El Progreso* is the first one in Spain and occurred only 7 years after Edwin Drake (1819-1880) drilled the first oil well in Pennsylvania. As indicated in the Mining Statistics, "*...there is a new industry that may be of incalculable future for the country*". In 1872 an attempt to distill the tar sands in the area was performed, operated by a hole dug on the north side of Peña Redonda (Dupuy de Lome, 1937).

Curiously, after the demarcation of *El Progreso*, a newspaper from Madrid called *La Gaceta de Madrid* (September 3rd, 1867), containing what it was published in the *Diario de Barcelona*, provided "*news on the discovery and exploitation of a mineral oil called petroleum*". Details on the opening of the first well in Pennsylvania by Drake were also given.

According to Gavala (1916), in 1860 there was an attempt to extract oil out of bituminous slates from the Grazalema Range. The presence of oil in the sulphur mines of Conil (Cádiz) was mentioned in 1894. In 1895 oil appeared when drilling a water well in the area of Jerez de la Frontera. In 1906 oil and ozokerite were found in the area of Villamartín. In 1907 gaseous emissions were observed near a farmhouse of Santo Domingo, close to Jerez, and a concession for oil was requested. In 1908 gas emissions were also observed in the fountain of Pambauco, west of Lebrija, next to the Guadalquivir River marshes, and the Oil Company of Pambauco was created (See *Revista Minera Metalúrgica y de la Ingeniería*, 1910, 345). Soon, after a host of foreign engineers (Marshall, Petit, Leblanc) and national ones (Mallada, Velázquez and others), studied this area, boreholes were drilled in

Figure 6. In 1937 or 1938, and during three years, the borehole of Chinchilla was drilled. Later, in the 1950s, another borehole was drilled (www.chinchillademonetaragon.com).

Figure 7. Zumaya borehole (Archivo General de Guipúzcoa Guipuzcoaco Artxibo Orokorra_OA06785).

Villamartín and Bornos (Cadiz), as well as several ones were drilled in Lebrija (Sevilla). Gavala thought that the source rocks were the clays with evaporite meterils of Triassic age, but the scarce of oil in these rocks made everybody aware of the possible existence of oil deposits in reservoir rocks of the area.

During those years, interest arose on the Basque-Cantabrian basin, where there were well known oil evidences, generally located in the continental facies of Purbeck or Weald. For this reason, some boreholes such as the Salvatierra one (Álava, Northern Spain), conducted by the Geological Survey of Spain in 1915, were drilled.

The First World War stimulated the search of oil resources and especially the application for concessions. Because of this, many oil companies were incorporated. A brochure of Sánchez de Toca (1917) entitled "The oil as a main product for our national economy", notes the emerging suggestions in favor of oil exploration and exploitation of national oil, as well as those for creating a state monopoly in the distribution sector. In 1920 the Geological Survey of Spain sent several geologists to visit the major oil-producing countries, to acquire some knowledge on the matter (Ríos, 1949). Also, foreign geologists such as Faison Dixon, who worked in the Gastain borehole (1923), came to Spain. Until then, boreholes did not exceeded 700 m of depth and the evidences found were scarce. But, in the 1920's boreholes deeper than 1,000 m began to be drilled, such as Ahedo (Burgos), Gastain (Navarra) and Ajo (Santander), along with shallower ones. Until the Spanish Civil War (1936-1939), a total of 11,000 m were drilled. Numerous indications were cut, but none of the boreholes were productive. At this time, a scheduled survey with geological criteria was performed (searching for structures and/or formations) and the first geophysical surveys were also carried out, such as that of the Geological Survey of Spain in the area of Garrucha, Almería (1932). However, certain geological knowledge was lacking, and "*in the 1920's, believing that under the Triassic surrounding the Demanda Range (Burgos) Permian materials were located, sediments that were oil productive in other parts of Europe, boreholes were drilled by a Swedish company in Palazuelos de la Sierra and Salguero of Juarros, with negative results*" (Ayala, 2007).

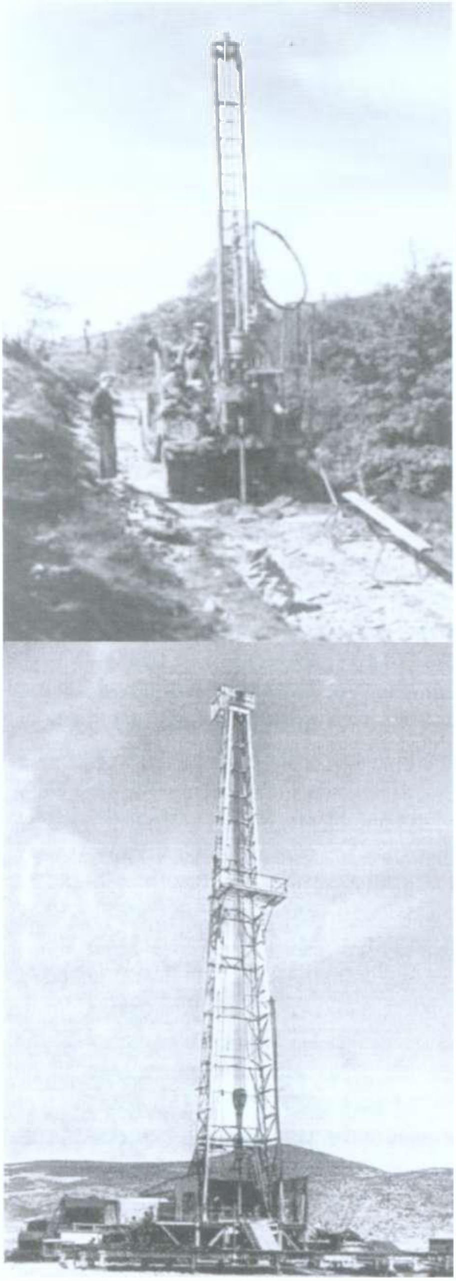


Figure 8. CIEPSA borehole in the Basque-Cantabrian Basin (Archivo Territorio Histórico de Álava-DAF-SCH-13760), and drilling rig of ADARO Company (*Industria Minera*, 1968).

In Table 1, we provide a list with the first main boreholes drilled in Spain (Mallada, 1910, Gavala, 1916, Dupuy de Lôme, 1937, *ABC* 1-Sep-1926, García Portero, 2004, López Peña, 2005, *La Vanguardia* 26-Sep-2006, Baquedano, 2007).

The company named Compañía Arrendataria del Monopolio de Petróleos Sociedad Anónima (CAMPSA) -founded in 1927 after the Law of Petroleum Monopoly of June 28th, 1927, was approved by the dictatorship of Miguel Primo de Rivera- was the first devoted to the petroleum industry in Spain. CAMPSA assumes a monopoly on the importation, processing, storage and distribution of oil, but not on the research and production areas (although these areas were also considered when it was founded). In 1937, during the Spanish Civil War, one of the parties (the Nationals) created a Survey section (belonging to the Department of Industry). However, it is not until the end of the Spanish Civil war that CAMPSA found evidences of petroleum in borehole N° 7 from the Zamanzas valley (Burgos), of 2,177 m of depth.

Until the foundation of CAMPSA, Shell and Standard Oil companies controlled the whole Spanish market and 80% of the global market. The strong economic interests led the USA and Britain to work hard in the destabilization and eventual overthrow of Primo de Rivera's dictatorship, founder of the Spanish monopoly on petroleum (http://es.wikipedia.org/wiki/CAMPSA).

4. OIL AFTER THE SPANISH CIVIL WAR

During the Civil War, three boreholes began to be bore, but drilling was interrupted by military activities. From these boreholes, only the one located in Tremp (Lérida) was finished, reaching 1,700 m of depth (Ríos, 1949). In the Hall containing the Library of the Republic (Salamanca Archive Series) there are several technical reports on the Isona boreholes, in addition to reports on the oil possibilities of the Tremp basin in 1937. We do not know if Ríos (1949) considered in this group the borehole of Chinchilla (Albacete), which reached more than 600 m of depth.

In 1937 a section devoted to prospection was created within CAMPSA Company, and the area between Pamplona (Navarra) and the Puerto del Escudo (Santander), an area with many evidences, began to be explored.

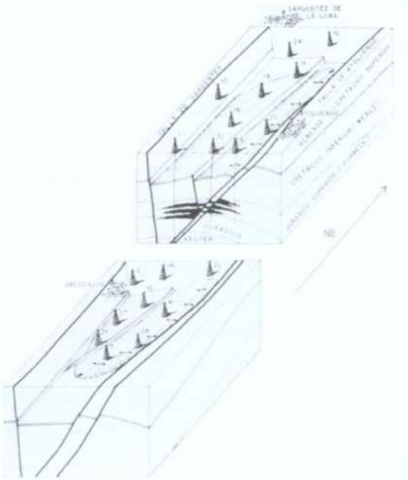


Figure 9. Oil discovery in Ayoluengo (1964) (*La Vanguardia Española y ABC Sevilla* 9-Junio-1964). Scheme of the Ayoluengo oil field (Hevia, 1998)

Site	Year	Company	Depth	
1.-Huidobro (Bu)	1900	Soc. de Sondeos de Huidobro	501	+
2.-Utrera (S)	1910		600	
3.-Salvatierra (Vi)	1911	El Estado (IGE)	200	
4.-Villamartín (Ca)	1915	El Estado (IGE)	377	
5.-Lebrija (Se)		Cía. Petrolífera de Pambauco	300	+
6.-Condado Treviño (Bu)			641/200	
7.-Polanco (S)		Solvay	700	+
8.-El Robredo-Ahedo (Bu)	1922		1010	+
9.-Elorrio (Bi)	1923		600	
10.-Leva (Bu)			600	+
11.-Gastain (Na)	1923	Soc. Petrolera-Iberoamericana (con la participación Interocean Oil C° de New York)	1660	+
12.-Aras (Na)			700	
13.-Jaizquibel (SS)	1923		615	
14.-Tona (B)	1929		700	
15.-Ajo (S)	1926-27	Soc. Petrolera-Iberoamericana	1200	
16.-Bornos (Ca)	1928-29	El Estado	500	
17.-Fuentoba (So)	1928-29	El Estado	398	+
18.-Ronda (Ma)	1932-34	Copropiedad Petróleos de Ronda	500	

Table 1. First main boreholes drilled in Spain.

The petroleum company Compañía de Investigación y Explotaciones Petrolíferas (CIEPSA), founded in 1940, discovered gas near Vitoria (Álava) in 1959. CIEPSA was subsidiary of the Spanish Company of Petroleum (Compañía Española de Petróleos-CEPSA), the first main petroleum public company in Spain (incorporated in 1929). CIEPSA was created with capital provided by CEPSA and Vacuum Oil Spain (Socony Vacuum Oil).

A systematic exploration of large areas of territory was performed by Spanish and foreign geologist (mainly Germans and Americans) under CAMPSA and the national company of mining research's (ADARO) -and later on CIEPSA- command. CIEPSA provided equipment capable to reach 2,500 m of depth, reaching 2,000 m in Oliana (Lérida) in the late 1940's. In 20 years more than 61,000 m were drilled (Ríos, 1959). Since 1950 Schlumberger tests begun to be performed (logging in exploration wells) in the boreholes of Peña Ortún, La Marina, Boltaña and San Lorenzo de La Parrilla. Also, CIEPSA found natural gas in Castillo, near Vitoria (Álava), in 1959. From 1963 to 1981 this fuel was extracted for the first time in Spain, drawing 33 Mm^3 that were transported through a pipeline of about 4 km long to diverse factories: BH (bicycles) and Esmaltes San Ignacio. CIEPSA also reached 5,000 m of depth in 1960 in a borehole conducted in Santa Cruz de Campezo, with a machine imported from USA, whose value exceeded 31 million pesetas (Baquedano, 2007).

Under the Decree of December 12th, 1952, oil research was declared of national interest and was supervised by the National Institute of Industry (INI), which could engage association with other entities. All reserves found along Spain, except those areas with existing permits or concessions, are also considered as a national property.

In 1950 George Cramer visited the Navarra region and found geological similarities with the State of Colorado (USA); then he decided to invest in oil in the Ebro basin. For this purpose, Valdebro was established in

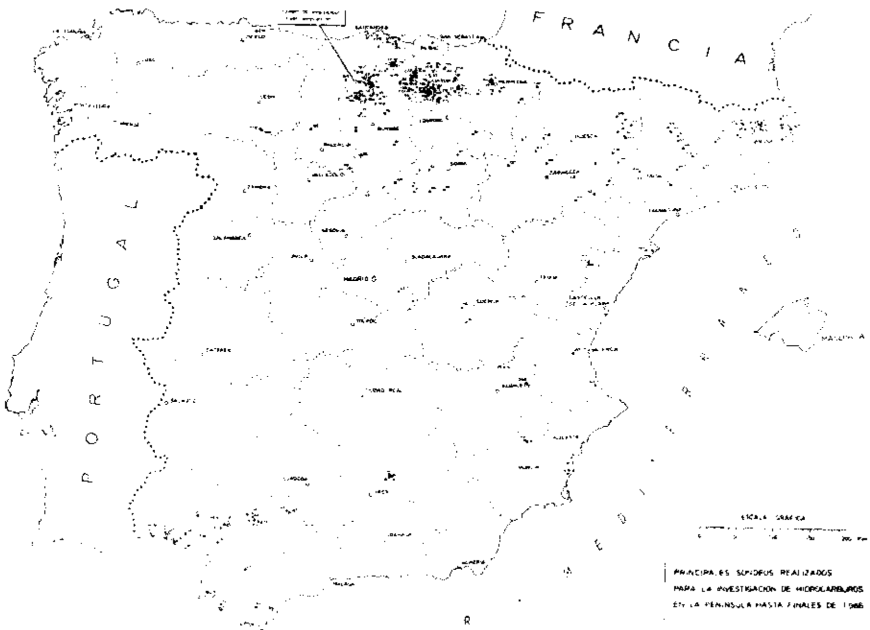


Figure 10. Location of major oil boreholes in Spain (Ríos, 1968). Most of them are located in the Basque-Cantabrian basin.

1953, a consortium formed by the National Institute of Industry (ADARO) and several USA companies (General American Oil Co. of Texas, Tyler Delta Drilling Co., and GSI). After the seismic survey of the subsurface geological structures, the Marcilla-1 borehole was drilled, reaching 3, 415m, but with negative results.

Some of the main boreholes drilled after the Spanish Civil War (Ríos, 1958) are listed in Table 2.

Site	Year	Company	Depth	
1.-Zumaya (SS)	1940	CAMPSA		
2.-Tudanca (Bu)	1941	CAMPSA	445	
3.-Valle Zamanzas-1 (Bu)	1942	CAMPSA	602	+
4.-Valle Zamanzas-2 (Bu)	1944	CAMPSA	820	+
5.-Valle Zamanzas-3 (Bu)	1945	CAMPSA	860	+
6.-Oliana (L)	1947-48	CIEPSA	2223	¿?
7.-Chiclana (Ca)	1947-49	ADARO	747	+
8.-Peña Ortún (Bu)	1947-50	CAMPSA	1246	+
9.-Burgo de Osma (So)	1949-50	CIEPSA	2212	
10.-La Marina (A)	1950-51	CIEPSA	1610	
11.-Dobro (Bu)	1951	CAMPSA	1221	
12.-Rojales (A)	1952	CIEPSA	1552	
13.-Villanueva de Ramplay (Bu)	1952-53	CAMPSA	2177	+
14.-Boltaña (Hu)	1952-54	CIEPSA	2124	
15.-Baena (J)	1953	ADARO	410	+
16.-Marcilla (Na)	1953	Valdebro	3415	
17.-Baeza/Bailén (J)	1953-54	ADARO (3 sondeos)		+
18.-Delica (Bi)	1953-54	CAMPSA	358	
19.-Castilfrío (So)	1954	Valdebro	2400	
20.-Zúñiga (Vi)	1954	CIEPSA-Socony Vacuum Oil	2050	+
21.-Chiclana (Ca)	1954-56	ADARO	1033	+
22.-Apodaca (Bi)	1955	CIEPSA	2535	
23.-S. Lorenzo de la Parrilla (Cu)	1955	Valdebro	2580	
24.-Iglesias (Bu)	1955-56	Valdebro	2180	
25.-Puigreig (B)	1956	Valdebro	3192	
26.-Bornos-Villamartín (Ca)	1956	Valdebro	3027	
27.-Leva (Bu)	1956	CAMPSA	580	+
28.-Matienzo (S)	1956	Valdebro	1950	
29.-Laño (Bu)	1956-57	CIEPSA	3501	+
30.-Alda (Na)	1956-57	CIEPSA	3540	+
31.-Almarchal (Ca)	*1956-57*	*Valdebro*	3045	+

Table 2. Main boreholes drilled after the Spanish Civil War (Ríos, 1958).

Until 1956 one or two oil research boreholes were performed per year, maximum three. From this year on to 1961 the number of boreholes drilled reached 11-13 per year, a number that increased after 1962 due to the Oil Law of 1958.

5. THE OIL LAW OF 1958 AND THE DISCOVERY OF OIL IN BURGOS

On December 26th, 1958, the Law on Legal Regime of Research and Exploitation of Hydrocarbons was approved. This is the first time oil was regulated independently of mining activities (this law would be complementary to the Mining Law of July 19th, 1944). The regulation implementing this Law was approved under the Decree of June 12th, 1959. This legislation strengthens the country's presence, thinking on the domestic supply, even though the international blockade of the United Nations to Francisco Franco's dictatorship (1950) had ended and agreements with the USA military bases (1953) had been signed. The main changes were that Spain opened to foreign capital (Chevron, Texaco, and other companies started to invest in our country) and holders of exploration permits had the obligation of conducting a minimum of activities.

In 1963 CAMPSA and AMOSPAIN (subsidiary of Standard Oil and Texaco) discovered gas in the Ayoluengo field (Valdeajos, Burgos) and, a little bit later (July 6th, 1964), oil was extracted from Ayoluengo I borehole of 1,349 m of depth. This was the first and only petroleum field in continental Spain.

Later, the extension of the petroleum field was delimited through 32 boreholes, a small site (10Km^2) with 2Mtons. At the beginning productions of 1000 barrels/day were reached, but it progressively diminished to 300/350 barrels/day in the 1970's and activity ceased in 2000, despite the attempts of increasing production by drilling new boreholes (up to 53). This was a small field, fragmented (associated to sandstones arranged in palaeochannels of the Purbeck facies) and with a bad quality petroleum. Because of that, petroleum was not refined but directly used as fuel in the glass industry, such as VICASA (Cantabria) and other from the Basque Country.

Later on, CAMPSA and AMOSPAIN found small petroleum fields in the vicinity of Ayoluengo: Tozo, Huidobro, and Hontomín (Hevia Cangas, 1989 y *La Vanguardia Española*, 26-Sep-68). Following CAMPSA's actions, other companies (Chevron, REPSOL, Northern Petroleum, and Ascent Production) began to investigate in this zone.

Thus, the Ayoluengo petroleum field has been active during 35 years. In 2002 the Spanish Society for the Preservation of the Geological and Mining Heritage-(SEDPGYM) proposed its transformation into a Petroleum Museum. This initiative has been assumed by the City Council and will include rooms devoted to geology, research and production of oil fields (*El Correo Gallego* 20-Jul-2008). The other petroleum field located in the surroundings that bore certain interest (Hontomín, in Jurassic limestones) will be used as a Technology Development Site for the sequestration of 100,000 tons of CO_2.

Gas was found in Serrablo (Huesca, Spanish Pyrenees) and was extracted from 1984 to 1990, when the oil field located in the Guadalquivir marshland began operations.

Studies on Spanish territories —such as the case of Guinea and Sahara, and the "off-shore" sites— will be considered on subsequent studies.

6. CONCLUSIONS

The first survey of oil production in Spain, well known as Tejón borehole, was conducted by the Sociedad de Sondeos de Huidobro in 1900, in Huidobro (Burgos). The concession of El Progreso is the first one in Spain and appear only 7 years after Edwin Drake (1819-1880) drilled the first oil well in Pennsylvania. At the begining of the 20th century the Basque-Cantabrian Basin become of interest, where different petroleum seeps appeared, usually located in continental facies, and the mining permissions were numerous, mainly after the 1st World War.

The company named "Compañía Arrendataria del Monopolio de Petróleos Sociedad Anónima" (CAMPSA) was the first devoted to petroleum industry, founded in 1927 after the Law of Petroleum Monopoly, of 28 June 1927, was approved.

In 1963 CAMPSA and AMOSPAIN (subsidiary of Standard Oil and Texaco) found gas in the Ayoluengo field (Valdeajos, Burgos). This was the first and only one petroleum field in continental Spain. At the beginning, productions of 1000 barrels/day were reached, that progressively diminished and ceased in 2000.

CAMPSA and AMOSPAIN found later small petroleum fields in the vicinity of Ayoluengo: Tozo, Huidobro and Hontomín. After CAMPSA, other companies (Chevron, REPSOL, Northern Petroleum and Ascent Production) began to investigate in this zone.

Thus, the Ayoluengo petroleum field has been active duting 35 years. In 2002 the SEDPGYM proposed its transformation into a Petroleum Museum. The other petroleum ield with certain interest in the surroundings (Hontomín, in Jurassic limestones) will be used as Technology Development Site for the sequestration of 100.000 t of CO_2.

REFERENCES

Ayala Carcedo, F.J. 2007. Minería Industrial (El petróleo y el uranio). In: SIEMCALSA (ed.), *La Minería en Castilla y León.* Junta de Castilla y León (SIEMCALSA), Valladolid, 82-83

Baquedano, K. 2007. *La búsqueda del petróleo en Álava.* Eusko Ikastunza, San Sebastián, 111 pp.

Dupuy de Lôme, E. (1937). Las investigaciones de petróleo en España. Boletín del Instituto Geológico y Minero de España. T. LIV, 4-73.

Gavala, J. 1916. Regiones petrolíferas de Andalucia. *Boletín de la Comisión del Mapa Geológico de España,* XXXVII, 27-211.

García Portero, J. 2004. *La exploración para hidrocarburos en el País Vasco.* Ente Vasco de la Energía, Bilbao, 8 pp.

Hevia Cangas, F. 1989. Aprovechamiento de los Hidrocarburos datos históricos. *Historia de la Geología.* Real Academia de Ciencias Exactas Físicas y Naturales. Madrid, 309-337.

Hevia Cangas, F. 2001. El petróleo. In: Ayala Carcedo, F.J. (ed.), *Historia de la Tecnología en España.* Valatenea, Barcelona, Tomo I, 213-218.

López Peña, C. 2005. *Memorias de un tiempo pasado 1907 (Ahedo de las Pueblas)-1982 (Madrid) de Andrés Peña Varona,* 134 pp. *ahedodelaspueblas.com/documentos/memoriasAPenaVarona.pdf*

Mallada, L. 1910. Yacimientos de petróleo y azufre de la provincia de Cádiz. *Revista Minera, Metalúrgica y de la Ingeniería,* LXI 25-28 and 41-42.

Maestre, A. 1864. *Descripción física y geológica de la provincia de Santander.* Imp. Gamayo, Madrid, 127 pp.

Maffei, E. and Rúa de Figueroa, R. 1872. "Apuntes para una biblioteca española de libros, folletos y artículos, impresos y manuscritos, relativos al conocimiento y explotación de las riquezas minerales y á las ciencias auxiliares." Imprenta J. M. Lapuente, Madrid. Reedited in *La Minería Hispana e Iberoamericana.* Cátedra de San Isidro. León II, 531 pp & III, 695 pp.

Mazarrasa, L. 1923. Estudio de las sustancias bituminosas de la provincia de Santander. *Boletín Oficial de Minas,* VII (75), 3-41.

Nuño, G. 1965. *El santero de San Saturio.* Espasa-Calpe, Madrid, 163 pp.

Querol, R. 1971. La estratigrafía española y sus posibilidades petrolíferas. *Industria Minera,* 121, 29-70.

Ríos, J.M. 1949. Las investigaciones de petróleo en España. *Notas y Comunicaciones del Instituto Geológico y Minero de España,* 119, 354-374.

Ríos, J.M. 1958. Posibilidades petrolíferas del subsuelo español en su relación con el origen del petróleo y sus condiciones de yacimiento. *Notas y Comunicaciones del Instituto Geológico y Minero de España,* 50, 1-46.

Ríos, J.M. 1958. Relación de los principales sondeos para investigación de petróleos llevados a cabo en España desde 1939. *Notas y Comunicaciones del Instituto Geológico y Minero de España,* 50, 47-94.

Ríos, J.M. 1968. Relación de las principales actividades para investigación de hidrocarburos llevadas a cabo durante 1967. *Industria Minera,* 94, 5-75.

Sánchez de Toca, J. 1917. *El petróleo como artículo de primera necesidad para nuestra economía nacional.* Imprenta Isidro Perales, Madrid, 189 pp.

Tornos, C. 1865. *Memoria sobre el beneficio de las sustancias bituminosas, presentada al Excmo. Sr. Ministro de Fomento.* Imprenta Nacional, Madrid, 56 pp.

Vallvé Bermejo, J. 1996. La minería en Al-Andalus. *Actas de I Jornadas sobre Minería y Tecnología en la Edad Media Peninsular.* Fundación Hullera Vasco-Leonesa, Madrid, 56-64.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

INFORMATION ABOUT PETROLEUM IN AMERICA PRIOR TO THE NINETEENTH CENTURY

Luis F. Mazadiego Martínez, Octavio Puche Riart and José E. Ortiz Menéndez

E.T.S. de Ingenieros de Minas, Universidad Politécnica de Madrid, Ríos Rosas 21, 28003 Madrid, Spain.
luisfelipe.mazadiego@upm.es

Abstract. The petroleum substances have been used a lot of centuries ago: bitumen has been used in Neolithic Period to fix head's hammer of stone and to set beads. The authors of this paper want to show the knowledge of bitumen and asphalt in South America until the 19th century through documents of Spaniards conquerors. Besides, we have done a comparative study between different words to design these petroleum products.

1. INTRODUCTION

Petroleum from natural springs was widely used by South American people long before the arrival of the Europeans. They covered their bodies with it to keep the dangerous and unbearable mosquitoes away and they used it for lighting and numerous medicinal applications. They extracted it from surface indications in the same way as Neolithic cave dwellers close to the Dead Sea or the inhabitants of Mesopotamia had done. Surface indications are the different chemical properties of gas, water, rocks and soil associated with nearby oil and gas occurrences or indicative of favourable conditions for their existence. They are classified into Direct Indications (originated by the presence in gas, water, rock and soil of disperse petroleum components, whether liquid, solid or gaseous) and Indirect Indications. Indirect Indications can be active (when the visible products on the surface are constantly renewed due to active underground circulation: this is the case of oil and gas sources and mud volcanoes) or fossils (when permanent renovation balancing losses due to surface oxidation does not exist. One example of this would be asphalt sand. Surface indications are what allowed petroleum substances to be discovered and used in numerous applications in ancient times. Then, as from the nineteenth century, surface indications constituted a valuable tool in the exploration of oil and gas strata (Mazadiego, 1994). Characteristic of these indications are their smell, gas bubbles in streams, irisation on the surface of water and asphalt deposits originated by the oil's heat-induced evaporation.

2. VENEZUELA

One of the first written references to the existence of petroleum products in America is due to Gonzalo Fernández de Oviedo y Valdés (Madrid, 1478-Valladolid, 1557), the Spanish historiographer and writer. During his lifetime he made five journeys to the American continent, being appointed Official Chronicler of the Indies in the year 1532. After his second sojourn in America, he published his *"De la Natural Hystoria de las Indias"* (1526), a summary and foretaste of what would be his most well-known book: *"La Historia general y natural de las Indias islas y tierra firme del mar océano"*, which tells the story of the discoveries made between 1492 and 1549. This book (Fernández de Oviedo, 1526), which went to 15 editions in a century, is a veritable encyclopaedia of anthropology and ethnography and, to some extent, is inspired by the works of Pliny the Elder.

Fernández de Oviedo wrote about petroleum after Juan del Junco and Gómez del Corral, two of his comrades-in-arms, told him of their experiences during the expedition of Jerónimo Lebrón up the river Magdalena in 1541: *"One day's distance from the village of Tora, where the brigs are going to land, there is a source of asphalt, a well which boils and runs out of the soil. It enters through the mountain at the foot of the sierra in large quantities. The Indians take it to their homes and cover themselves with it to relieve their tiredness and strengthen their legs whilst the Christians make use of it to caulk their brigues"*.

When writing about Cubagua, also called Isla de las Perlas or Pearl Island, Fernández de Oviedo explains that it is a small, flat island and, after referring to some plants and animals, mentions that it has a good port to the North and that the island of Margarita is only a league away (Forbes, 1958). He describes the western end as follows: *"On the western tip there is a fountain of an oily liquor next to the sea, so abundant that the liquor or asphalt runs over the sea, leaving signs more than two or three leagues from the island and even from there comes the smell of this oil. Some of those who have seen it say that it is called "stercus demonis" by the naturals and others "petroleum" and others "asphalt" and those who call it in this latter manner do so because they believe that it is the same type as that from lake Asphaltide about which many authors write. They say that this liquor from Cubagua is much used in many things and for different diseases and from Spain it is requested with much insistence due to the experience had of it by the doctors and the persons who have used it to remedy their illnesses. I have heard it said that it is a very useful remedy for gout and other illnesses from the cold because they say that this oil is very hot"*.

The first Spanish town to be established on American soil, New Cadiz, was built in the vicinity of this source of petroleum. There, the colonials established themselves to exploit the pearl fisheries. At its height, the revenue received by Spain from the pearl fisheries was similar to that supplied by Peru in gold. One year after the publication of the book by Fernández de Oviedo, Juana I 'The Mad', Queen of Castile (1479-1555), daughter of Ferdinand II of Aragon and mother of Charles I of Spain/Charles V, Holy Roman Emperor, addressed a letter to the Royal Officials in New Cadiz on the island of Cubagua, dated 3 September, which reads: *"Some people have brought to these Kingdoms the oil that is in a fountain on that island (...) and here it has appeared to be useful"*, ordering all the vessels leaving Cubagua for Spain to load as much of the substance as possible. This command was faithfully followed as is corroborated in three documents, two dated in 1539 and the third one in 1540, currently deposited in the General Archive of the Indies in Seville. The first shipload of this product from Cubagua arrived at the Casa de Contratación (House of Trade) in Seville in the ship Santa Cruz, from where it was sent to the Queen. Apparently a further barrel of petroleum was received in December 1540. However, different natural phenomena, such as the tidal waves of 1541 and 1543, the destruction of the oyster beds and the death of the Indians who worked in them, led to the town and the island being completely abandoned by the Spaniards, although records exist showing that the island was populated for some time afterwards. Nevertheless, these geological phenomena accelerated the end of the petroleum trade with Spain. Some years later, in 1552, Francisco López de Gómara, the historian, included in his *"Hispania Victrix" (First and Second Parts of the General History of the Indies)* a comment on the petroleum of Cubagua, which some people looked upon as a simple repetition of what had previously been reported by Fernández de Oviedo.

In 1589, the priest Juan de Castellanos (1522-1607), as chronicler of what occurred in the kingdom of New Granada, wrote in his epic poem "*Elegias de Varones ilustres de Indias*" (Elegía XIII, Canto 1), referring to Cubagua, that "*Its dry beaches have a fountain/to the West where beats the sea/of a liquor excellent and proven/ in the common use of medicine:/which in the time of currents/can be seen above the sea/in a space of three leagues, with patches/that are usually strong and very wide*". Another of the places highlighted in sixteenth and seventeenth century documents is Lake Maracaibo. Alvaro Alonso Barba (1559-1662) mentioned in his "*Arte de los Metales*" (1640) ("*The Art of Metals in which is declared the Manner of their Generation, and the Concomitants of them") that "asphalt was known in these lands because it is abundant in the mountains of Los Chiriguanas. If no more is known about it, this is because it is in a hostile area where warring tribes live*". These mountains are situated near Lake Maracaibo and form part of Colombian territory although the deposits extend as far as Venezuela. In the middle of the sixteenth century, the pirates that reached American soil were in the habit of taking refuge in Maracaibo where they could mend their ships with pitch. The port where they moored was San Timoteo, who, with the passing of the years, ended up by being declared the patron saint of crooks and swindlers.

3. PERU AND ECUADOR

Information about petroleum outflows in the Santa Elena peninsula in Ecuador was relatively abundant. The members of Francisco Pizarro's expedition to Peru had already seen them and, in connection with them, Pedro Cieza de León (1520-1554) said that *"it was true that there were mines where very hot tar flowed"*. The discovery of fossilized bones of Pleistocene fauna made some chroniclers, such as Father Agustín de Zarate or even Pedro Cieza de Leon, fall into the error of believing the natives' legends, according to which these bones belonged to cruel, godless giants, punished with a shower of fire. Nearly a century later, Antonio de León Pinelo (1595-1660), in his "*El Paraíso en el Nuevo Mundo*" (1655), backed this theory: *"At the tip of Santa Elena bones come out with the pitch from the deepest part of the Earth where they had been buried under the mountains"*.

Agustín de Zárate, referring to the petroleum, wrote in his "*Historia del descubrimiento y conquista de las provincias del Perú*" (1555) that *"at a cape called Santa Elena by the Spaniards, there are some outflows of pitch or tar used by the natives to mend their boats"*. Some years later, Father José de Acosta, who travelled widely through the Viceroyalty of Peru between 1569 and 1583, wrote in his *"Historia Natural y Moral de las Indias"* (1590): "*In a place on cape Santa Elena there is a fountain of pitch which in Peru they call "copey" and which sailors use to cover their rigging*". Fray Reginaldo de Lizárraga y Obando (Badajoz, Spain, 1540 – Asunción, Paraguay, 1615), referring to these organic compounds in Santa Elena, wrote in his "*Descripción breve de toda la tierra del Perú, Río de la Plata y Chile*" that they were commonly used by the natives to cure wounds, always provided when the nerves weren't damaged, which would appear to indicate that they were used to fixed fractured bones.

Towards the end of the nineteenth century, in the year 1878, these surface indications were exploited by private Colombian and Italian investors until in 1909 they became the property of Carlton Graville Dunne, who, in turn, sold them to other companies until in 1919 they became the Anglo Ecuatorian Oilfields. In 1921, the Ancon Number 4 well, was productive with 30 barrels a day and exploitation of these wells continued in Santa Elena until they were declared exhausted in 1962.

As defended by García Tapia in "*Del Dios del fuego a la máquina del vapor*" (1992), it would seem that in the coastal region the Indians obtained the asphalt from natural wells and then boiled it in pots to make it more unctuous. They covered themselves with this product to protect themselves from the cold when diving in the cold waters of the Pacific Ocean. The Jesuit José Eusebio de Llano Zapata, who spent many years in Peru, refers in his work of 1759 to the medicinal uses given to petroleum. He says: "*Thus, in their state of simplicity and innocence, they enjoy an energetic virtue against poison, weak nerves, uterine suffocations, the effects of vermin and the suppression of menstruation. For these ills, they take, in wine, from 10 to 15 drops internally; and, externally, smeared on*". As regards external use against mosquitoes, he says: "*No es esto sin misterio en aquellas gentes, pues por medio del olor fuerte que despide el betún se defienden de los que, infestando aquellos países, incomodan a los caminantes.*" (*This is not without mystery in these people because by means of the strong odour given off by the bitumen they defend themselves against* [the mosquitoes] *which, infesting those countries, inconvenience the wayfarers*". In 1789, Juan de Velasco, in "*La Historia del Reino de Quito*" points out that "*The Indians mix limestone with a type of asphalt already described by Gomara. This marvellous mixture is one of the Indians' many secrets and knowledge, which we have lost due to the carelessness of the first conquistadores. They use it to join stones firmly together*".

4. CUBA

The city of Havana was then called Carene because the boats went there to be "*carenados*" (careened). Gonzalo Fernández de Oviedo y Valdés wrote of Cuba that "*on the island and not far from the sea, a liquor or bitumen, like pitch, flows out of a mountain in sufficient quantity to caulk chips. This material, which continuously enters the sea, forms large lakes or patches on the sea or quantities above the waves, from one part to another, depending on the winds' movement or how the sea on that coast moves and runs. Quinto Curcio, in his fifth book, says that Alexander the Great arrived at the town of Memi, where there is a large cavern or cave, in which there is a fountain that spreads a great quantity of bitumen, so it is easy to believe that the walls of Babylon were joined together with bitumen because there are also some like that in New Spain*", adding that another had been found at Panuco, better than the one in Cuba. In 1565, Nicolás Monardes, the Sevillian doctor, mentioned in his "*Historia Medicinal de las cosas que se traen de nuestras Islas Occidentales*" that "*bitumen is a type of tar that abounds on the island of Cuba, with springs close to the sea*", adding that there it was used for medicinal purposes, whereas the Europeans used it to caulk their chips. Along these same lines, Gerónimo de Huerta in his translation of Pliny's "Natural History", wrote the following: "*The island of Cuba has two very notable things, which are a valley where a large quantity of stones as round as canon balls are produced, and a fountain, in Puerto del Príncipe, from which comes marvellous bitumen for caulking ships*". In this connection, Bernal Díaz del Castillo (1492-1580) wrote in his "*Historia Verdadera de la Conquista de la Nueva España*" (1575) that "*we agreed that it was the captain Pedro de Alvarado on a ship supposedly called San Sebastián, owing to the fact that it was leaking, although not too much, that it should be caulked on the island of Cuba*".

5. MEXICO

In ancient Mexico there is evidence of the use of "*chapopotli*", a word made up of "*tzauc*" or "*tzacutli*" (cement) and "*popochitli*" (perfume), in the waterproofing of canoes and pottery and for adding to copal resins in religious ceremonies. Copal, an Aztec word deriving from "*copalli*", is a plant which produces resin and even today is used to manufacture varnish. Bernal Díaz del Castillo referred to this mixture when, in connection with Yucatán, he said that "*on reaching the river Guazacualco* (close to the present-day city of Veracruz) *we entered* *another river to which we gave the name of San Anton, and there a ship that was leaking heavily was caulked"*. This author's references to petroleum substances are numerous: "*The chief came to talk to Cortes and asked him why we had returned* (to the Yucatán Peninsula, an area with abundant surface indications of petroleum) *and he said it was because a ship was leaking and he wanted to dress (adobar) it"*. With the word "adobar", Díaz del Castillo was describing the ship's caulking.

Fray Bernardino de Sahagún (1529-1590), the Spanish historian, lived in Mexico from 1529 studying the language, customs and myths of the Aztecs. In one of his books, "*Historia General de las cosas de Nueva España*" (1540) (General History of the Things of New Spain), he wrote that *"the natives use staves, made with rattan, into which they introduce aromatic products, which they prepare by mixing bitumen, which they call "chapopotli", fungi and roses"*. According to Forbes, there were two types of bitumen: one used to perfume ceremonial sticks; the other, "*tzictli*", much appreciated by the women. The latter was mixed with yellow wax until a gelatinous mass was achieved which was chewed and which prevented caries. This "*tzictli*" was referred too by Juan de Cárdenas in his "*Problemas y Secretos Maravillosos de las Indias*": "*This must be the reason why they chew this black bitumen, called by the Indians "zictli", which takes their hunger away"*. Similarly, in "*Efemérides astronómicas arregladas al meridiano de México (1775-1783)*" the following can be read: "*It was God, creator of all things visible and invisible, who on Friday, the 21st day of February of 1783, made us see on the water in the ditches, close to the Sanctuary of Guadalupe in Mexico, a sort of petroleum which in the future would be useful"*.

Ancient indication	Begining of exploitation	Exploited after the nineteenth century?	Name of the petroleum product	First reference	Use
Island of Cubagua (Venezuela)	Pre-Columbian	Explorations carried out to assess the reserves	MENE	Gonzalo Fernández de Oviedo (1535)	Medicinal Caulking of boats
Lake Maracaibo (Venezuela)	Pre-Columbian	YES	MENE		Caulking of boats
Cape of Santa Elena (Ecuador)	Pre-Columbian	YES (up to 1962)	COPEY COPEI COPÉ	Agustín de Zárate (1555)	Caulking of boats Medicinal
Cuba	Pre-Columbian		CHAPOTE CHAPOPOTE	Gonzalo Fernández de Oviedo (1535)	Caulking of boats
Trinidad and Tobago	Pre-Columbian	YES (Royal Dutch Shell & Texaco)	PICHE	Sir Walter Raleigh (1595)	Caulking of boats
Yucatán and Veracruz (Mexico)	Aztecs Mayas	YES	CHAPOPOTLI CHAPOPOTE CHAPAPOTE	Bernardino de Sahagún (1540)	Caulking of boats Medicinal Religious ceremonies

Table 1. Some words to designate to organic's compounds in America

6. ISLAND OF TRINIDAD

The first written reference to the Pitch Lake or Asphalt Lake of Trinidad, dates back to 1595. In February of that year, Sir Walter Raleigh (1552-1618), the English explorer, courtier and writer, set sail from England in search of the fabled land of El Dorado. When he landed in San José de Oruña or St. Joseph, then capital of Trinidad, he went to reconnoitre a place called Parico "*where there is an abundance of a substance which the natives know as piche and which the Spaniards call pitch clay. There is so much of this pitch that the boats that come here from all over the world make use of it. We made some experiments to make sure that its use is good for mending boats, with excellent results, even more so because this pitch doesn't melt in the sun's heat as occurs with the pitch found in Norway*". The lake covers an area of half a square kilometre and, in some points, has a depth of almost 50 metres. The pitch is made up of an emulsion of 40% oil, 30% clay and another 30% of water. However, it is thought that neither Raleigh nor Dudley, to whom Anglo-Saxon literature attributes the lake's discovery, ever actually saw it, intuiting its existence when they discovered pitch carried by water to the coast where they landed.

The Reverend Griffith Hughes (1707-1758), a British naturalist and author, included in his "*The Natural History of Barbados*" (1750), some notes on St. Joseph, previously the capital San José de Oruña, founded by the Spaniard, Antonio Sedeño. This island was discovered in 1498 by Christopher Columbus and, in 1802, became part of the British Empire. The following can be read in this book: "*A bituminous exudation can be found in the hills of St. Andrews, close to St. Joseph, that is a dirty black. The method by which they obtain this product is to make a hole in the ground or a pit near the point where it filters through. Then it is concentrated by gravity, with a thin film being obtained which is distilled on the surface. It is then when it is gathered in pots. The months of January, February and March are the best period of the year for doing this. It is so inflammable that it can be used in lamps. In addition, it has excellent medicinal properties, being used with success in disorders of paralysis and of a nervous type and to cure eruptions of the skin. It is also used to pour over horses when they are exhausted*". In 1789, Alexander Anderson wrote in "*An Account of a bituminous Lake or Plain in the Island of Trinidad*" about a bituminous lake or plain, known by the name of Pitch Lake or Asphalt Lake; by the French people called La Bray, "*from the resemblance to, and answering the intention of, ship pitch*", describing the areolae formed on its surface and stating "*I take this bituminous substance to be the bitumen asphaltum Linnaei. A gentle heat renders it ductile; hence, mixed with a little grease or common pitch, it is much used for the bottoms of ships, and for which intention it is collected by many, and I should conceive it a preservative against the Borer, so destructive to ships in this part of the world.*" The borers are marine molluscs that, in larva state, cling to any submerged wood object, boring tunnels of up to 30 cm long.

The German scientist Alexander von Humboldt (1769-1859), also referred to this lake in a letter addressed to the minister of Saxony in the Court of Madrid, baron de Forell, dated in 1800: "*This clay is so poor in native salt that it can barely be seen under the microscope. It contains more than 0.3% petroleum and is the origin of the pitch in Trinidad, in Buen Pastor on the coast of Paria and in the same gulf of Carraca, a gulf formed, according to the geological tradition of the Guaiguerys Indians, by an earthquake and which still appears to be in communication with the volcanoes of Cumucata, which throw up sulphur, hydrogen and hot, hydro-sulphuric water.*" He obtained these data during one of his journeys to Venezuela, Cuba and Trinidad. On the other hand, the natives were of the opinion that the origin of the lake's asphalt was linked to alligator excrement as both were found in bogs and swamps.

7. WORDS TO DESIGNATE OIL'S SUBSTANCES

Most of the surface indications used first by the natives and then, centuries later, by Europeans were either exploited commercially or at least investigated by oil companies. To an extent, they are the most tangible example of the information that indicates, in the initial stages of a fossil fuel exploration campaign, the existence of these filtrations at surface level.

The words used to designate these products are numerous and characteristic of the different geographical areas where the surface indications appeared. One of the most frequently repeated, particularly in Central America, is *chapapote* (pitch, tar, asphalt). The first definition of *chapapote* can be found in "*Historia General de las cosas de Nueva España*", a codex by Fray Bernardino de Sahagún: "*Chapopotli is a bitumen that comes out of the sea, and it is like Castilian pitch, easily separated, and the sea throws it in with the waves (…) and those who inhabit by the sea go pick it up from the shore*". The word "*chapopotli*", from the Nahua culture, is made up of the words "*tzacutli*" (cement, adherent) and "*popochtli*" (perfume) and is used to refer to the thick and strongly smelling bitumen. The words *chapapote* and *chapopote*, very common in parts of northern Spain, derive from *chapopotli*.

"*Mene*" is another of the most frequently used words in America, particularly Venezuela, to the point where there is an abundance of places or geographical accidents close to bituminous or asphalt lakes with this name. Another very common word in America is "*copey*" (or "*copei*"). This word of the indigenous Taino people, was initially used to refer to the resin of a tree. Starting in the sixteenth century, it was also used to describe the petroleum or *petrae oleum* that comes from natural springs. Subsequently, this word was transformed into "*copé*.

REFERENCES

Cieza de León, P. 1541. *Descubrimiento y conquista del Perú.* (Part II). Ed. Zero (1984), 364 pp.

De Acosta, J. 1590. *Historia Natural y Moral de las Indias*. Imp. De León, Sevilla, 491 pp.

De Sahagún, B. 1540. *Historia General de las cosas de Nueva España*. Editorial Historia 16 (1987), Madrid, 429 pp.

Díaz del Castillo, B. 1575. *Historia verdadera de la conquista de la Nueva España. Biblioteca Americana*. Ed. Historia 16 (1991), 636 pp.

Fernández de Oviedo y Valdés, G. 1526. *Sumario de la Natural y General Historia de las Indias*. Ed. Historia 16 (1986), Madrid, 170 pp.

Forbes, R.J. 1958. *Studies in ancient technology*. Leiden (Holland), 220 pp.

García Tapia, N. 1992. *Del Dios del fuego a la máquina de vapor.* Ambito-Instituto de Ingenieros Técnicos de España, Valladolid, 364 pp.

Mazadiego, L.F. 1994. *Desarrollo de una metodología para la prospección geoquímica en superficie de combustibles fósiles. (Part I).* Ph. D. Polythecnical University, Madrid. 423 pp.

Monardes, N. 1565. *Historia medicinal de las cosas que se traen de nuestras Indias Occidentales*. Sevilla, 324 pp.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

THE UNDERSTANDING OF RESOURCES AND KNOWLEDGE OF RAW MATERIALS, AS PRESENTED AT THE BIG WORLD EXHIBITIONS IN THE 19TH CENTURY

Marianne Klemun

Department for History, University of Vienna, Dr. Karl-Lueger-Ring 1, 1010 Vienna, Austria.
Marianne.klemun@univie.ac.at

Abstract. It has been often emphasized that World exhibitions demonstrated nationalism, imperialism, consumption and technological rise, so to speak, as their incarnation. In addition to that, they offered a stage for training and the propagation of a new concept of resource, connecting national uniqueness, availability and technological feasibility like never before in history. For the time being, this aspect has been neglected on the Viennese World Exhibition by the rich literature and that is the reason for this paper to be focused on that matter. World exhibitions were not only self-referential, but also promoted knowledge transfer and dealing with new questions connected to this way of understanding resources. At the Viennese World Exhibition in 1873 the outstanding significance of the realm of minerals as a priority field was expressed at the centre of the World Exhibition, so to speak, as a signifier of the foundation which raw materials seemed to have laid for any civilization. Indeed, this reference played a decisive role in all reports, since all explanations started describing the mineral resources. Apart from overviews, a collection of 500 stone cubes from the territory of the Monarchy was something special. It gave evidence of the variety of possibilities for the building sector, and immediately corresponded to the start of the great Ring Project -the expansion of the city of Vienna, locked up within its medieval boundaries, towards a modern metropolis. This unique collection of 500 cubes of the same size is still preserved these days at the former Mauerbach Monastery.

1. INTRODUCTION

Let me start with a quotation that provides a frame for my topic and research: "Wherever one was looking in the wide spaces of the World Exhibition, to whichever Gallery of the Industrial Palace one went, one observed rich objects from the first group of the World Exhibition, the materials from the realm of minerals, of mining and steel and iron works; the coal, iron and steel treasures of Europe's cultural states; the mineral and metal treasures from Turkey, Persia and India were presented. Most significant and dominated by the clear spirit of sciences appeared the coal, iron and steel expositions of Germany, with Freiburg in Saxonia, the university of German mining, being at the forefront" (Richter, 1877).

By these words, Professor of Political Science in Prague, Karl Thomas Richter began his treatise on "The Progress of Culture" (Richter, 1877), a paper dedicated to the World exhibitions and a paper that particularly deals with the Viennese and Philadelphian events of 1873 and 1876. This statement gives evidence of the contemporaries' new point of view regarding raw materials, as a link between pure science and application, which will be the topic of the following study.

It has been often emphasized that World exhibitions demonstrated nationalism, imperialism, consumption and technological rise, so to speak, as their incarnation (Kretschmer, 1999). They are showpiece productions of historicism and sciences. Both semantically and visually monumentality, abundance, speed, figures, statistics, expansions, sensations, novelties, and topicality, are connected to form a phantasmagoria. This statement is superelevated by the insignia of the new age, steel or iron and glass, both given their significance by the construction of progress. Under the roofs of industrial halls and crystal palaces, as particularly technological implementations and supported by light effects, exotic ornaments, both goods and machines, but also goods of knowledge of the most different kinds were exhibited. These "places of pilgrimage to the fetish of goods" (Benjamin, 1991), as Walter Benjamin called the exhibitions, offered a kind of education by way of entertainment, edification by way of displaying encyclopedic knowledge as well as identity development-serving patterns of competition and comparison between the European national states, so to speak. And they offered something else, a stage for research, training and propagation of a new concept of resource as such, connecting pure sciences with application, national uniqueness, availability and technological feasibility like never before in history. For the time being, this aspect has been neglected by the rich literature on the World exhibitions (Rydell, 1992), and especially on the Viennese World Exhibition, and that is the reason to focus this paper on that matter.

World exhibitions always present that what the Western world has in common. At the Viennese Rotunda, Emperor Franz Joseph and the organizers of the World Exhibition propagated in 1873 the gigantic bourgeois world of Liberalism as a feast for the people and as an advertisement show of peace in support (Fuchs, 2000) of a politically, economically and artistically revived Danubian Monarchy. Being a stock exchange for ideas as well as a trading place, it supported the exchange of knowledge, art and raw materials. Great Britain, which had become the heir of the European great powers after the Napoleonic wars, made a start. The economic doctrine of mercantilism was left behind, and as a result of Manchester Liberalism, the free trade treaty with France from 1860 occurred. The London World Exhibition of 1851 served for the purpose of extending Britain's claim to leadership on the way towards modern global trade (Haltern, 1971; Greenhalgh, 1988). The dynamics of the idea of the World Exhibition became obvious in Paris in 1855, where the role of art was included. Now, this goods show was considered a document of spiritual values. It was there where the artist Gustave Courbet proclaimed the programme of Realism, as it was to become of utmost significance for the age. Fascination on natural products and raw materials developed particularly in London, when, for the first time, rubber and jute were extolled and lino was exhibited.

It was biographies such as that of oil expert Hans Höfer von Heimhalt (1843-1924) that I became interested in the way resources were part of these exhibitions. Since Höfer's visit to the Philadelphia World Exhibition in 1876 on behalf of the Trade Ministry of the Habsburg state, he was essentially stimulated to become committed with oil in the future. After visiting the exhibition in Philadelphia, where he made contact with the idea of oil, he travelled around North America to see special places in order to write a book about the oil industry in that country ("Erdölindustrie in Nordamerika") (Höfer, 1877). Encouraged by the World Exhibition, it was the first comprehensive book on a new and quickly flourishing industrial branch. This study had a supporting effect on the early stages of Galicia's still-developing oil industry. Also, Höfer was the first person to point out the importance of water shutoff in boreholes and the advantages of the Canadian drilling method. He also defended the anticlinal theory, whose application was to result in rapid success in most oil producing areas.

Travelling through the North American oil producing areas stimulated specialization in this field of knowledge, something he dealt with until the end of his life. As a professor at the Coal and Steel University of Leoben, he edited the most important handbook about oil in a global perspective. This study consisted of 5 volumes and 5000 pages (Höfer and Engler, 1912-1919). Still today, it is a very famous and one of the most important studies, well known among oil experts.

Höfer's example perfectly illustrates the fundamental function exhibitions had in stimulating geologists and coal and steel experts' research. These exhibitions created new fields of knowledge that resulted in new resources. From these explanations concludes the first point of my considerations.

2. WORLD EXHIBITIONS AS EXPRESSIONS OF SCIENCE AMONG THE PUBLIC

World exhibitions were not only self-referential for the states but also brought about a dynamic knowledge transfer and new questions connected to this way of understanding resources among the public. They were public expressions of science. In the past of Earth Sciences; politics, Earth Sciences and the public used to be considered entirely separate areas. Unbridgeable gaps were thought to lie between them (Geikie, 1962; Adams, 1954). The few connections that existed were interpreted by science as a process of popularisation towards the public. It was expected that scientists modified, translated and even simplified their results for laymen. However, by stating this description one overlooked that this dichotomous concept was based on strategies made by scientists themselves, who, on the one hand, increasingly enforced a strict borderline to distinguish themselves from laymen and, on the other hand, isolated themselves from politics in order to give themselves a public air of creativity and meaningfulness. Only recent studies have shown that sciences and scientists are always subject to a process of social, political and cultural interaction, in the context of direct contact between science and the public (Latour 1999, p. 119; Felt 2002, p. 49).

I am not interested in showing how individual scientific results become part of the larger public in the sense of a knowledge transfer. My aim is to find out more about the texture of interferences of sciences with the public among exhibitions, as well as the potential of those interferences for sciences themselves. Nobody less than the chemist Lyon Playfair, in charge of setting the way exhibits were displayed at the Crystal Palace in London in 1924, had appealed to the nationalist attitude: Britain's imperial age was said to be in danger if its citizens did not accept what every European citizen had already learned, i.e. "the fact that successful competition can only be attained by an attentive study of science by making their sons of Industry themselves disciples of Science" (The British Empire, 1924, 113; Rydell, 2000, 129).

3. EXHIBITIONS AND EXPERTS

Exhibitions were planned by experts, and it was them who processed the facts presented. But they did not only contribute to the preliminary stages of the exhibitions, but also to assessing them.

As a matter of fact, the voluminous literature covering exhibitions, usually produced by experts and scientists, gives evidence of the contribution of science and of the dynamic aspect of the knowledge transfer. This scientific literature was mostly published once the exhibition had finished. On the Viennese exhibition, 95 official monographic reports were written, putting together more than 5,000 pages (Officieller Ausstellungsbericht, 1873-1877). In a comprehensive and reflecting way, they listed the variety presented at the exhibition (Vivenot, 1873). Results were judged on, and conclusions were drawn in a summarizing way. Reports from commissions and juries, as well as one's own impressions, were introduced in a broad range of literature which cannot be presented in detail here. At the preliminary stages, the complete elite of science, bureaucracy and industry (Kupelwieser, 1873; Rosthorn, 1874) contributed to the event. For the Paris World Exhibition, for example, the First Class of the exhibition, dedicated to that "trade whose main purpose was the production of raw materials" (Viebahn and Schubarth, 1856), was headed by nobody less than Elie de Beaumont, Member of the Imperial

Exhibition Commission, Secretary of the Academy of Sciences, Inspector General of Mining, Professor of Geology at the Imperial Collége de France, as well as the President of the Geological and Meteorological Society. From one exhibition to the next one the changes and the focus of the states were perceived and assessed. For example, the Prussian report on the Paris World Exhibition noted:

"However, if we consider that 50 years ago mining and steel production were hardly existing in France or at least were at such a low stage of development that everybody who wanted to deal with it had to study in Germany, the energy and the means employed by France to develop this important part of the national wealth cannot be denied the respect it deserves" (Viebahn and Schubarth, 1856).

Whereas for Britain, the "various kinds of coal" were considered the foundation of industrial predominance, the lack of fossil fuel was given as the reason for the decline of Sweden, which had once been at the forefront of the production of iron (Viebahn and Schubarth, 1856).

Canada, Britain's colony, succeeded with quite a special appearance at the London World Exhibition, thanks to the Director of the Geologic Commission, William Logan: Under the roof and across the whole room, a gigantic canoe was suspended, surrounded by furs, antlers and Indian headdresses; the raw materials were presented on the floor. William Logan's collection of minerals also was one of the Canadian contributions to World exhibitions. Its completeness and system was absolutely in accordance with the demands of serious scholarship from this century of stock-taking sciences. It gave evidence of the multitude and variety of minerals. The London Geological Society honoured Logan with a medal for his contribution to Paris. In his home country he was given a higher salary for extending the Geologic Survey (Schroeder-Gudehus, 2000). Expressively, Logan had presented his exhibits under the motto of usefulness. However, the ore samples were minerals whose existence was proven, but they were hardly mined, or only in particular cases. This was a hint for potential investors, whose help was needed to start the mining of raw materials. In Paris in 1855, Logan's collection was awarded the *Grande Medaille d'honneur.* In contrast with London, hints at previously unknown coal seams in the entire territory were added in Paris (Zeller, 2009). It was due to Geology that growing self-confidence could spread all over Canada.

As we have seen in the example of Canada, World exhibitions were not only retrospective, but also prospective. The Viennese Exhibition focused on including the Orient, particularly Persia, which would be explored in the future regarding its geology.

Already at the London Exhibition in 1851 a classification system was developed for all goods to be exhibited (Arenstein, 1863; Auerbach, 1999). For the Paris Exhibition, Le Play (engineer and head of mines in France) had developed this system further. We know from the history of sciences that the 18th century is considered the century of classification, thanks to the leading role that Botany and Natural History played. Now, this kind of classification, initially restricted to the natural sciences, conquered the entire material world in the second half of the 19th century. The way the exhibition's design was organized became structurally manifest by this scientific approach. The entire world of production, it was stated, could be compared to botanical gardens, whose design was always based on a pattern of order. At the World exhibitions, according to the scientific way in which it was processed, the world of raw materials presented itself in a well structured way.

The entire Exhibition in Vienna was structured into 9 groups, the first one being characterized by resources. In the context of raw materials, the products of mining and steel production formed the First Class and, in this group, further structuring provided an overview on production areas by help of geological maps. These subgroups were structured according to the most important aspects, such as raw materials, coal, organization of surveys, coke, new methods to display metals, non-precious metals (with the exception of iron, copper, lead, tin, zinc, cobalt and stones), and precious metals (gold, silver). Also, the second group, machine construction, was dominated by a raw material: iron (Rosthorn, 1874). The third group focused on machines and instruments, as well as devices of the natural sciences and those designed for teaching. The fifth group was dedicated to the processing of raw materials: steel goods, goldsmith's art, porcelain and glass. The sixth group referred to the textile industry, the seventh one to furniture and so on. And the eighth group referred to works of the fine arts (Wolf, 1877; Arenstein, 1863; Officieller Ausstellungsbericht 1873-1877).

With the exception of the latter two groups, raw materials from the world of minerals played a key role for all systemic elements. In this manner, the meaning of resources was networked in many ways and was anchored as being predominant.

4. THE ROLE OF GEOLOGY FOR THE EXHIBITION CONCEPT ITSELF

Although in this study I have looked at the literature covering the exhibitions, I would like to shortly sketch the role of Geology for the exhibition concept itself, taking the Viennese World Exhibition as an example. At the Viennese World Exhibition, the outstanding significance of the realm of minerals as a priority field was expressed at the centre of the World Exhibition, so to speak, as a signifier of the foundation which raw materials seemed to have laid for any civilization. Indeed, this reference played a decisive role in all reports, since all explanations started describing mineral resources. In previous exhibitions priority had been given to coal industry, but new aspects played an important role in order to present the Habsburg power, serving to the development of its identity: almost in the centre of the Industrial Palace, under the central space with its cupola spanning over 102 m, as well as in the Eastern Gallery towards Northern Court 14b, the Geological Survey ("Geologische Reichsanstalt") was allowed to present itself and the "available products of the Habsburg Empire's realm of minerals". By way of maps and publications on its completed survey, this institution "gave splendid evidence of its more than twenty years of activity" (Amtlicher Bericht, 1874-77; Gr.I/Sect.1, p.5). Apart from statistics and overviews, a collection of minerals comprising 1,600 pieces and structured into three main sections documented the state's material world: ores, fossil fuels and building materials were authentically exhibited here. Special mention must be made of the 500 stone cubes collection from all the territories of the Monarchy. It gave evidence of the variety of possibilities for the building sector, and immediately corresponded to the start of the great Ring Project -the expansion of the city of Vienna, locked up within its medieval boundaries, towards a modern metropolis after 1872. This unique collection of 500 cubes of the same size is still preserved these days at the former Mauerbach Monastery, and today is still used to train restorers.

REFERENCES

Adams, F.D. 1954. *The Birth and Development of the Geological Sciences*. Dover Publications, New York, 506 pp.

Amtlicher Bericht über die Wiener Weltausstellung im Jahre 1873, 1874-1977. Ed. by the Cetralcommission des deutschen Reiches für die Weltausstellung.

Auerbach, J. A. 1999. *The Great Exhibition of 1851: A Nation on Display*. Yale University Press, pp. 280.

Arenstein, J. 1863. *Österreichischer Bericht über die Internationale Ausstellung in London 1862*. Kais.-königl. Hof- und Staatsdruckerei, Wien, 740 pp.

Benjamin, W. 1991. Das Passagen-Werk. In: Tiedemann R. (ed.), *Gesammelte Schriften Walter Benjamins, V/1+2 Vol.* Suhrkamp, Frankfurt am Main, 1350 pp.

Felt, U. 2002. Statt Aufklärung. Zur Problematik spezifischer Formen der Wissenschaftspopularisierung. *Österreichische Zeitschrift für Geschichtswissenschaften*, 13(1), 138-42.

Fuchs, E. 2000. Nationale Repräsentation, kulturelle Identität und imperiale Hegemonie auf den Weltausstellungen: Einleitende Bemerkungen. In: Fuchs E. (Ed.), *Weltausstellungen im 19. Jahrhundert. Comparativ.* Leipziger Universitätsverlag, Leipzig, 8-14.

Greenhalgh, P. 1988. *Ephemeral Vistas: The Expositions Universelles, Great Exhibitions and World's Fairs, 1851–1939.* Manchester University Press, Manchester, 245 pp.

Höfer, H. 1877. *Die Petroleum-Industrie Nordamerikas in geschichtlicher, wirtschaftlicher, geologischer und technischer Hinsicht.* Commissions-Verlag von Faesy & Frick, k.k., Buchhandlung, Wien, 166 pp.

Höfer, H. and Engler C. 1912-1919. *Das Erdöl. Seine Physik, Geologie, Technologie und sein Wirtschaftsbetrieb.* Verlag von S. Hirzel, Leipzig, 5 vols..

Geikie, A. 1962. *The Founders of Geology.* Macmillan & Co. Ltd, 1897, London, 486 pp.

Haltern, U. 1971. Die *Londoner Weltausstellung von 1851. Ein Beitrag zur Geschichte der bürgerlich-industriellen Gesellschaft im 19. Jahrhundert.* Aschendorff, Münster, 397 pp.

Kupelwieser, F. 1873. *Das Hüttenwesen (Gruppe I, Section 2 und 3). Officieller Ausstellungs-Bericht.* General-Direction der Weltausstellung, Verlag der k.k. Hof- und Staatsdruckerei, Wien, 110 pp.

Kretschmer, W. 1999. *Geschichte der Weltausstellungen.* Campus, Frankfort und New York, 303 pp.

Latour, B. 1999. *Pandora's hope: essays on the reality of science studies.* Harvard University Press, Cambridge Massachusetts, 324 pp.

Officieller Bericht, 1873-1877. *Officieller Ausstellungsbericht.* General-Direktion der Wiener Weltausstellung, Verlag der k.k. Hof- und Staatsdruckerei, Wien, 95 Vols.

Richter, K. Th. 1877. *Die Fortschritte der Cultur. Einleitung in das Studium der Berichte über die Weltausstellung 1873.* H. Dominicus, Praha, 223 pp.

Rosthorn, G. 1874. *Erzeugnisse aus Kupfer, Zink, Blei, Zinn, Nickel und deren Legierungen.* Officieller Ausstellungsbericht, General-Direktion der Wiener Weltausstellung, Verlag der k.k. Hof- und Staatsdruckerei, Wien, 29-41.

Rydell, R.W. 1993. *World of Fairs. A Century of Progress.* University of Chicago Press, Chicago, 269 pp.

Rydell R.W. 2000. Wissenschaft im Dienste der Macht – Macht im Dienste der Wissenschaft. In: Fuchs E. (ed.), *Weltausstellungen im 19. Jahrhundert. Comparativ.* Leipziger Universitätsverlag, Leipzig, 127-142.

Schroeder-Gudehus, B. 2000. Um ein Bild der Nation: Kanada auf den Weltausstellungen des 19. Jahrhunderts. In: Fuchs E. (ed.), *Weltausstellungen im 19. Jahrhundert. Comparativ.* Leipziger Universitätsverlag, Leipzig, 29-43.

The British Empire Exhibition, 1924. Exhibition of Pure Science Arranged by the Royal Society. *Nature,* 113 (14.6), 863.

Viebahn, G. y Schubarth, 1856. *Amtlicher Bericht über die Allgemeine Pariser Ausstellung von Erzeugnissen der Landwirthschaft, des Gewerbfleißes und der schönen Kunst im Jahre 1855.* Verlag der Deckerschen Geheimen Ober-Hofbuchdruckerei, Berlin, 832 pp.

Vivenot, F. 1873. *Bergbau und Hüttenwesen. Montanproducte (Gruppe I, Section 1.)* Officieller Ausstellungs-Bericht ed. by Generaldirection der Weltaustellung 1873. Verlag der k.k. Hof- und Staatsdruckerei, Wien, 1-19.

Wolf, H. 1873. *Die Steinwaaren. (Gruppe IX, Section 1).* Officieller Ausstellungs-Bericht, General-Direction der Weltausstellung 1873. Verlag der k.k. Hof- und Staatsdruckerei, Wien, 1-43.

Zeller, S. 2009. *Inventing Canada: Early Victorian Science and the Idea of a Transcontinental Nation.* McGill-Queen's University Press, Montreal, 372 pp.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

FINDING AND USING PEAT AND COAL IN NORTHERN ITALY BETWEEN THE EIGHTEENTH AND THE NINETEENTH CENTURY: FIELDWORK INSTRUCTIONS IN THE WRITINGS OF CARLO AMORETTI

Libera Paola Arena

Università degli studi di Bari, piazza Umberto I, Bari, Italy.
libera.arena@gmail.com

Abstract. Between the Eighteenth and the Nineteenth century the need to find new sources of fuel increased throughout Europe. The Governments of the European States began to show a significant interest for new mineralogical resources, such as peat and coal. Also in northern Italy this kind of political and economical attitude was evident, although later than in other European regions. The research, the extraction and the use of these kind of fossil fuels were regulated by new laws and by new political bodies, like the "Consiglio delle Miniere" *(Council of Mines)* in Milan during the Napoleonic period. Carlo Amoretti was a member of this Council and wrote two practical instructions for the officers sent on the field to find fossil fuels in the Italian Kingdom during the early 1810s. Thus, in order to achieve this aim, the practice of geological travel was developed for identifying mineralogical and bituminous deposits, as well as for observing natural phenomena and, more precisely, for studying the features of the Earth's surface. Amoretti, even if was a polymath and not a specialized scientist, made several geological trips in the northern regions of Italy giving his contribution to the profitable collaboration between political bodies and scientific communities.

1. INTRODUCTION

At the beginning of the Nineteenth century the geological science had a remarkable development and was the object of a significant interest from the most important European political institutions. Governments and state bodies began to get interested in geo-mineralogical studies on new natural resources exploitable by man. According to Armando Frumento (1991), wood and iron were the main economical resources in Europe until the mid-Eighteenth century, but the evident and increasing lack of wood, became a cause of general worrying for the governments. For a long time forests had been little cared. The reckless looting, the careless management of forestland, fires, the lack of rules, the excessive use of woods for sheep-farming and cultivation were the main cause of the deforestation (Vecchio, 1974; Visconti 2003; Visconti, 2008). In the mid-Eighteenth century there was still not a balanced and wise use of forests. Consequently the governments began to control and regulate the use of woods and tried to find new sources of fuels, like peat and coal.

In the early Nineteenth century, northern Italy was in a significant backwardness concerning the exploitation of peat and coal, if compared with other European States like England and France (Torrens, 1998). In northern Italy, as stated by Carlo Amoretti (Baillet, 1803, pp. 346-347), coal was generally little exploited, even if some initiatives were taken in order to encourage its use. In fact, at the end of the Eighteenth century the Habsburg Government promoted in Lombardy some awards for searching new fuels. Thus, in 1782, Ermenegildo Pini (1739-1825), important geologist, professor of chimical and natural science, but also "scientific officer to mines" for the Austrian Lombardy, published an essay about peat (Pini, 1785). With this report the Habsburg Government of Lombardy aimed to improve the public knowledge and the use of this new natural fuel, namely peat. Amoretti specified that, at the time, the utility of peat was known in the spinning mill, for the evaporation oven, in the oven of lime, for glassworks and manufactures of majolica (Baillet, 1803, pp. 346-347). Also the "Società Patriottica" (*Patriotic Society)* of Milan tested and used peat in many circumstances with good results and consequently motivated its use, but without any significant results. In fact in the early Nineteenth century in Italy, even if several peat deposits had been identified, very few of them were exploited. People generally preferred to choose still wood, in spite of the efforts of the Government, mainly for a physical and moral reasons: the ground were used for cultivation and grazing; the prejudices about the dangers on the health were very strong and finally existed a real ignorance about what were, where find and how use peat and coal (Amoretti, 1810, pp. 12-14). On the contrary, England was the first European state to understand and promote the heating power and the economic value of this fossil fuel. In France, after the Revolution, the potential of coal was also recognized and the Government began to encourage those who devoted themselves to this research (Maironi da Ponte, 1785; Amoretti, 1811, pp. 1-2).

2. CARLO AMORETTI AND THE "CONSIGLIO DELLE MINIERE"

Figure 1. Carlo Amoretti (Oneglia 1741 - Milano 1816). Litograpy of C. De Marchi, 1816 (Amoretti, 1824).

During the Napoleonic Government in northern Italy, at the beginning of the Nineteenth century, a new attitude seemed to take place with regard to the exploitation of peat and coal. In the newly established Italic or Italian Kingdom (*Regno Italico)* some important legislatives dispositions were adopted in order to control the exploitation of forests. In 1805, Daniele Felice, the Home Secretary of the Napoleonic Government, promoted the establishment in Milan of the "Commissione dei Boschi e delle Miniere" (*Commission on Forests and Mines),* in order to regulate forestry and mining (Frumento, 1991). Among the ten members of the Commission there was Carlo Amoretti (1741-1816), librarian of the Ambrosiana Library, interested in natural science and secretary of the Patriotic Society. It is interesting to note that the members of this new state body under the Napoleonic Government, represented different professional backgrounds and skills: men of science (professors of chemistry, naturalists or doctors), as well as scholars and polymaths working as officers for the Government, as in the case of Carlo Amoretti.

Amoretti (Fig. 1) was born in Oneglia (Liguria) and after had studying the ancient and the modern languages and the philosophy, he went in Pavia to became a priest and continued to study physics and theology. He lived for some years in Parma were he deepened his studies. He became an eclectic scientist and scholar, living most of his life in Milan as an estimated translator, editor and author of scientific works and periodicals (Labus, 1824; Grillo, 1846; De Felice, 1961, Arecco, 2003). Amoretti can be defined an "intellectual-traveller", as others in that period, sent to evaluate the mining potential of several parts of northern Italy. As in the case of other members of the Council of Mines, his interests in mineralogical and litho-stratigraphical studies in the field, contributed to the reconstruction of the geological history of the explored areas.

The "Commissione alle Miniere e ai Boschi", born in 1805 with a temporary charge, became, during the following three years, a solid government body of the Napoleonic state with the name of "Consiglio delle Miniere" (Vaccari, 2004). Officially established in 1808, this Council had the duty to find and identify the mineralogical and bituminous deposits of the Italic Kingdom. The staff of the Council included three members (Pini, Isimbaldi, Amoretti); two inspectors (Corniani, Brocchi); two engineers and a secretary. The Council met once a week in the Palace of the Public Garden of Milan (Frumento, 1991). This state institution provided a significant contribution to the development of the geo-mineralogical studies on the Italic Kingdom. In particular the Council promoted several geo-mineralogical researches and travels with the aim of surveying and identifying potentially exploitable minerals and fossil fuels, including peat and coal, in order to complete a mineralogical map of the Italic Kingdom, as planned by Pini's proposal of 1809 (Frumento, 1991). The Council was also committed to carry out experiments in order to understand how to use these fossil fuels. Consequently the Napoleonic government, through the activities of the Council of Mines and the fieldwork of its travelling officers, planned to encourage the study, the exploitation and eventually the systematic use of these natural resources.

3. TWO INSTRUCTIONS FOR FIELDWORK ON PEAT AND COAL

Following the request received from the Napoleonic Government through the Council of Mines, Amoretti wrote and published two texts of instructions for specific fieldwork: "Della Torba e della lignite" (*On peat and brown coal:* Amoretti, 1810) and "Della ricerca del carbon fossile" (*On search of coal*: Amoretti, 1811), in order to remove the general belief about the supposed danger of the smoke and the smell of these fossil fuels when burnt, due to common ignorance on their real substance. These essays represented the aim of the political power to increase the general interest on the economic potential of these fossil fuels. The original manuscript on the coal (Fig. 2) has been found in the collection of Amoretti's papers kept in the "Istituto Lombardo Accademia di Scienze e Lettere" in Milan (ILASL), while the manuscript related to the 1810 paper has not been traced to date. An electronic version of both essays is available at the Braidense National Library of Milan (BNB, 0125/12-13, Sala Foscolo.05). In these instructions, in order to encourage the search of peat and coal, Amoretti provided details about how, where and why it was necessary to look for these fossil fuels. So, these sort of practical guidelines provided the basic tools needed to undertake a mineralogical fieldwork. The main recipients of these instructions were the officers sent in the field by the Government for collecting all the useful information - in particular for localizing the occurrence and identifying the type of the deposits - in order to compile a census of the fossil fuel deposits. The collected data were organized in some tables which could be found at the end of the two published essays. In both Amoretti's instructions three main topics can be identified: mineralogical definitions; uses and economic benefits; search, extraction and depuration works. It is interesting to note that Amoretti gave a particular attention not only to the technical and practical aspects of the instructions, but also to more scientific pieces of information about the nature and the origin of these fossil fuels. However, the political-economical aim of these works clearly supported the assertion of the great utility and effectiveness of

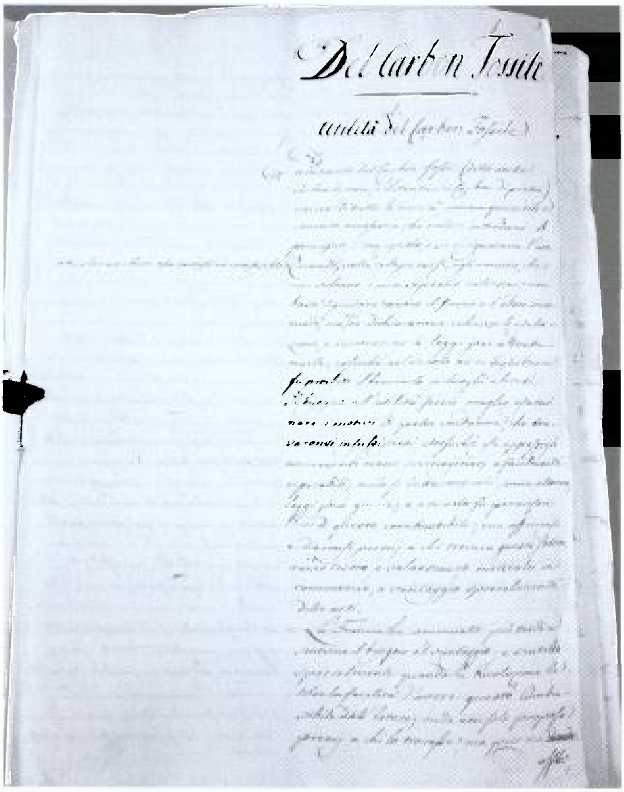


Figure 2. "Della ricerca del carbon fossile" (*On search of coal).* First page of the manuscript (ILASL, paper 1, file 1, folder 11).

the exploitation of peat and coal, in particular when compared with wood.

3.1 Mineralogical definitions

In order to overcome the ignorance on peat and coal, Amoretti provided a description of the origin and the formation of these substances. Peat was presented as a surface deposit of a soft and black pile of grass and seedlings build-up during a long time-span (Amoretti, 1810, p. 10). Brown coal was, like coal, a deep deposit and represented the recent phase of decay of resin plant (Amoretti, 1810, p. 11). Finally, the mineral matter of coal derived from the complete dissolution of resinous plants mixed with clay. Amoretti (1811, pp. 7-12) listed the different qualities of coal and indicated fat coal as the best fuel for the forges. Also the main theories on the origin of coal expressed between the end of the Eighteenth and the beginning of the Nineteenth century, were mentioned as follows (Amoretti, 1811, pp.13-15).

Vegetable Origin: coal is formed by the bituminous substances of plants mixed with clay. This was the theory adopted by the famous scientist Georges-Louis Leclerc, count the Buffon (1707-1788) but also by the French geologist, Barthélemy Faujas de Saint-Fond (1741-1819) and other scientists.

Animal Origin: coal is formed by animal fat mixed with clay. This was the most popular opinion.

Volcanic Origin: coal comes from underground volcanoes which also produced bituminous substances. The water had splitted these substances in little particles that, once deposited, had created layers of coal. This was the theory of Eugène Louis Melchior Patrin (1742-1815), French naturalist and mineralogist.

The first two theories considered coal as product of big catastrophic events which buried forests and animals. The last one was different because coal was considered a product of underground volcanoes. Reading these pages, we can understand how was important, for Amoretti, to combine scientific explanations and technical data, in order to give to his readers a complete picture of the geological resources exploitable by men.

3.2 Uses and economical benefits

After the discussion of the scientific ideas on the formation of the fossil fuels, it was still necessary to understand that the use of peat and coal was not a danger for health and could instead provide economical benefits. In fact, peat had more lasting flame, burned slowly and was cheaper than wood (Amoretti, 1810, p. 21); coal at equal weight had double fire action and worked more faster with less expense than wood (Amoretti, 1811, p. 6). After removing the impurities, coal and peat could be used for many different activities such as all kind of factories and forges, slaked lime and bricks furnaces, bread ovens, for the heating of greenhouse and public places or for cooking and heating in military camps. For these uses, different branches of the Government were interested in peat and coal like the Minister of Internal Affairs, of War, of Finance and also the Navy.

In addition, coal's impurities could be collected and reused with two methods based on condensation, thought in England and used also in French. Consequently, the tar was used as insulating material for the ships; the smoke for producing the "nerofumo"(black smoke) color; the oil for greasing wheels and the gas for lighting. In this way the waste products of coal became new useful products for many other different human activities (Amoretti, 1798; Amoretti, 1811, pp. 44-46). At this stage it was clear that different political branches of the Italic Kingdom's government had economical interest in the exploitation of coal and peat. However, in spite of this political attitude, many popular prejudices on the use of these fossil fuels survived.

3.3 Search, extraction and depuration works

Amoretti was charged to write these instructions mostly in order to give technical guidelines about the method of search, extract and purification peat and coal. Thus, Amoretti provided detailed pieces of information about searching possible traces of deposits, on testing specimens, on the procedures of mining and depuration (Amoretti, 1810, pp. 23-32, pp. 39-42 ; Amoretti, 1811, pp 20-46).

According to Amoretti, as peat was not so far from the surface, the ground containing it was usually swampy, soft and elastic. Traces of coal could be found, generally, in secondary and lateral valleys or in mountains between layers of sandstone.

Amoretti was also convinced on the effectiveness of a particular method for identifying mineral or bituminous deposits and water sources: the "Elettrometria Sotterranea" *(underground electrometric method)*. It was based on the use of a particular instrument (the "verga divinatoria") and on physical sensations felt by people able to perceive the supposed polar nature of some underground substances like water, metals or coal (Amoretti, 1801). This method, accepted by Amoretti, was rejected by many scholars, because it was based on personal interpretations. The argument of the "Elettrometria organica e minerale" was very discussed in Italy between the 18th and 19th century. (De Frenza, 2005).

In order to evaluate the quality of the deposit and the possible utility of mining it, Amoretti considered necessary to extract a sample of coal or peat using a particular instrument, called "Trivellone" (Fig. 3). A wooden model of this tool was available at the main office of the Consiglio delle Miniere in Milan. In both the instructions, Amoretti described this instrument which allowed to drill the ground (Amoretti, 1811, pp. 22-26). The extracted sample was analyzed in order to evaluate the possibility of mining. In the case of peat, this phase of work was not difficult because the deposits were near the surface, but extracting good samples of coal or brown coal was instead more laborious. Consequently, before to start mining, it was necessary to undertake an accurate evaluation which considered three main aspects: quality, quantity and costs. In the first place it was necessary to evaluate the extension of the vein of fossil fuel. Then the deposit could be extracted if, after burning the sample, the test had shown a high, clear and durable flame, the smoke was reduced and the earthy residuals were few. Finally it was necessary to consider all the costs concerning the mining activities: workers, excavation, tools, transport. This latter aspect depended on the localization of the deposits: if a good deposit was localized in a difficult place for organizing the works of extraction, it could not be exploited. In conclusion, only if the vain was rich, the samples had passed the fire testing and the previsions on mining costs were not so expensive, it was possible to start mining the coal deposit.

The extraction procedures were very different between peat and coal mining. In fact peat, being a surface deposit, required not a great effort to be removed: the common practice consisted in extracting parallelepiped pieces of peat with a particular spade (Fig. 4) and put them in a specific way in a place for drying them (Fig. 5). On the contrary, coal, being a deep deposit, needed a great effort to be treated and digging mines was not a simple work. There were many hazards to avoid, like the inflammable gases produced by coal that caused many dangerous explosions (Singer, 1994). The extracted fossil fuels were usually full of impurities and could not be used successfully in several applications. The humidity could be removed by a slow combustion which eventually provided dry fuels ready to use. The duration of burning, defined three purging ways: toasting, carbonizing and kneading with lime. Peat or brown coal were placed in a cylindrical oven, on a layer of bundles (Fig. 6). An iron cover and a layer of soil prevented air from entering. During the burning, the peat / brown coal's volume decreased; the cover fell and more soil had to be added to cover the oven (Baillet, 1803). The way to burn coal was the same as for peat: a round hole was dug in the ground and filled with pieces of coal on a layer of twigs, finally covered with ash (Fig. 6).

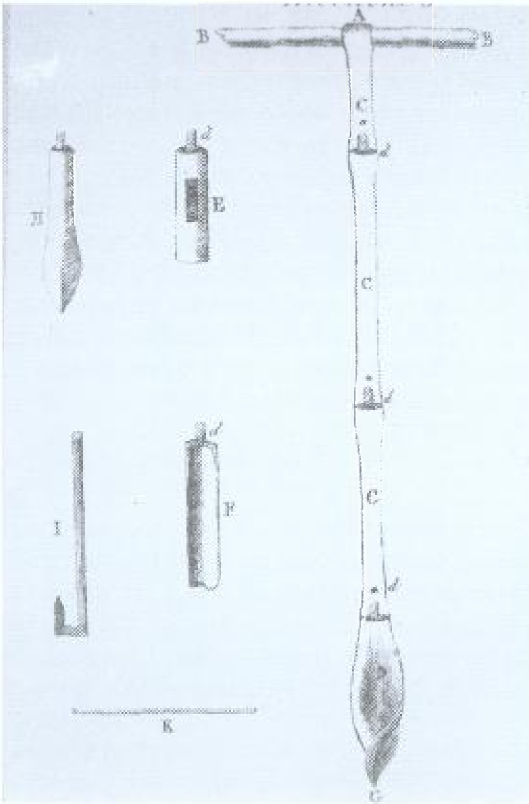


Figure 3. The "Trivellone". Amoretti described this instrument used for drill the ground in order to pull out samples of peat or coal for testing (Amoretti, 1811, p.22).

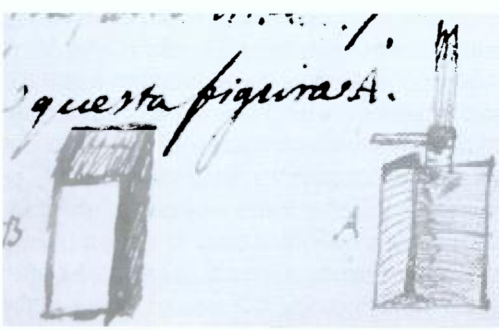


Figure 4. Tool for extracting peat. A spade with elongate edge which could cut peat in a parallelepiped shape (ILASL, paper 4, file 1 folder 11).

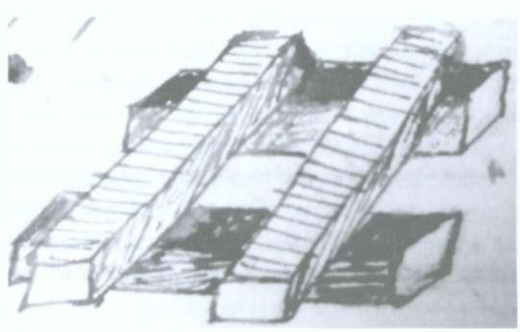


Figure 5. Dray peat. Way to put parallelepiped pieces of peat for dry them in the best condition (ILASL, paper 1, file 1 folder 11).

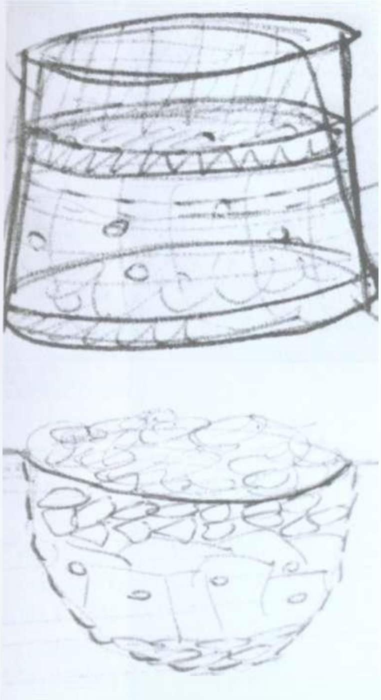


Figure 6. The process of combustion of peat and coal according to Amoretti, 1803 and Amoretti, 1811 (drawings by Libera Arena).

4. AFTER THE INSTRUCTIONS: THE MINERALOGICAL TRAVEL

After having learned the scientific and, above all, the technical information about peat and coal, the government inspectors were sent to undertake mineralogical journeys in order to locate, verify, analyze and coordinate the excavation of fossil fuels in the territories of the Italic Kingdom. These geo-mineralogical journeys, made in several parts of northern Italy, allowed the Government to collect data and pieces of information about peat, brown coal, coal deposits and also many other geological aspects (Vaccari, 2005; Candela 2009). This information could be used in order to draw a mineralogical map of the Kingdom (Visconti, 1990) even if this project remain, unfortunately, only an idea without any realization.

During the Habsburg Government, as secretary of the "Società Patriottica" and later under the Napoleonic Italic Kingdom as a member of the "Consiglio delle Miniere", Amoretti made many trips in order to check the presence of fossils fuels (Vaccari, 2005). During his life he travelled in several parts of northern Italy, as shown by many unpublished letters and manuscripts that he wrote during his travels and are now kept in the library of the "Istituto Lombardo Accademia Scienze e Lettere" in Milan (ILASL). An other important evidence of Amoretti's interest in travel (Fig. 7) may be found in his most known work, the "Viaggio da Milano ai tre laghi" (Amoretti, 1794), published in six edition: 1794, 1801, 1806, 1814, 1817, 1824. This book was a sort of guide for "curious tourists" interested in art and history, but mainly in natural science and written based on the Amoretti's unpublished letters. Most of this handwritten letters (ILASL, folder XI, XVIII, XXIV) shows the importance of the geological and mineralogical observations and refer to trips undertaken for searching peat and coal. For example. In 1797 Amoretti and Galeazzo Fumagalli travelled to Moltrasio, near the Lake Como in Lombardy, with the aim to search and make observations of the particular coal that was found there. Amoretti called it "asfalto" (*asphalt)* for its smell and appearance. This travel was promoted by the "Società Patriottica" in order to aquire more information about this coal and to evaluate the utility of its possible exploitation. A few years later, in 1800, Amoretti went to Cadibona, near Savona in Liguria, to search coal using the underground electrometric method. His fellow traveller was Vincenzo Anfossi, a young dowsing man. Here Amoretti found a particular coal called "Libro del Diavolo" (*Book of Devil*) as its layers splitted into thin sheets, on a limestone bottom. He carried out some tests on the collected samples and the results showed that this coal did not swell like the English one and contained a rich part of bitumen.

5. CONCLUSIONS

The writings and the manuscripts of Carlo Amoretti give us the opportunity to reconstruct an interesting part of the history of mineralogy and mining in northern Italy between two century of relevant intellectual

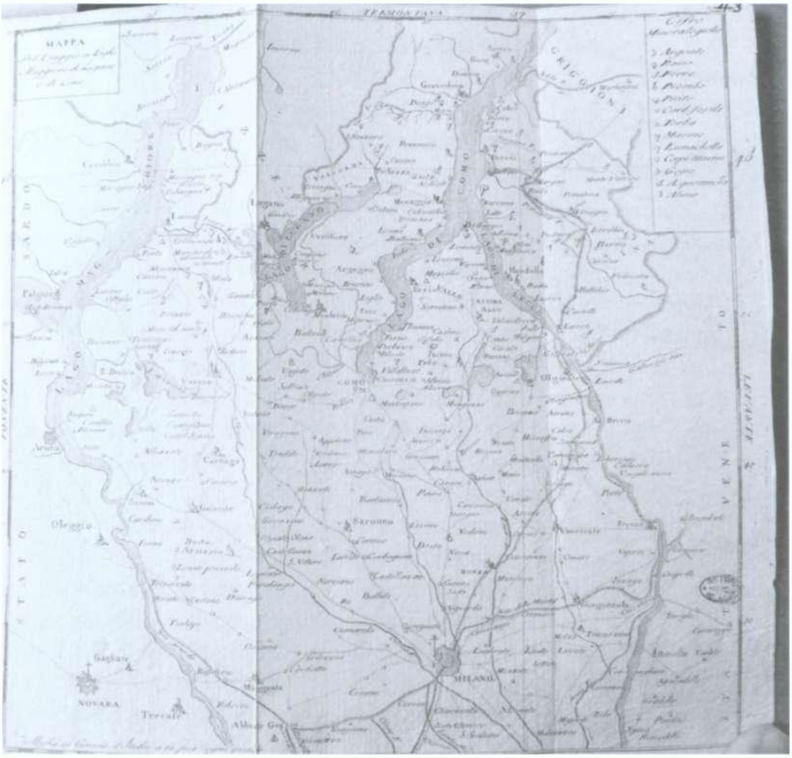


Figure 7. Map of Amoretti's travels in his "Viaggio da Milano ai tre laghi" (Amoretti, 1806).

development, when the need of searching new fossil fuels had stimulated a profitable cooperation between the scientific world and the political power of the different local governments that changed in a short period between the 18th and the 19th century in northern Italy. In fact the "Società Patriottica", before, and the "Consiglio delle Miniere", after, even if supported by different power (Habsburg and Napoleonic) had made both some important initiatives to promote the use of peat and coal. The activities of Carlo Amoretti allow us to understand the scientific knowledge, the techniques, the travels and also the political purposes related to the search of fossil coal in northern Italy, particularly in the early Nineteenth century. This interesting result of a scientific and political growth would not be possible without the symbiotic relationship between science and economical political menagement, carried out, in particular, by the Council of Mines and by the scientists-officials who travelled all over northern Italy, searching useful minerals and fossil fuel resources, like coal and peat. Within this contest, a little but significant contribution was given by Carlo Amoretti, an eclectic polymath and officer of the Government, interested in geo-litho-mineralogical features of the Earth's surface.

REFERENCES

Amoretti, C. 1794. *Viaggio da Milano ai tre laghi, di Lugano, Maggiore e di Como e né monti che li circondano.* Galeazzi Giuseppe, prima edizione, Milano. Altre edizioni: 1801, 1806, 18014, 1817, 1824.

Amoretti, C. 1798. Sul Carbon fossile, e sul Catrame che sen ricava. Osservazioni tratte dall'opera del cittadino Faujas-Saint-Fond. In: Amoretti, C. (ed.), *Opuscoli Scelti sulle scienze e sulle arti, vol. XX*. Giuseppe Marelli, Milano, 52-60.

Amoretti, C. 1801. Ricerche storico fisiche sulla rabdomanzia. In: Amoretti, C. (ed.), *Opuscoli Scelti sulle scienze e sulle arti, vol. XXI*. Giuseppe Galeazzi Stampatore, Milano, 393-411.

Amoretti, C. 1810. *Della torba e della lignite, combustibili che possono sostituirsi alle legni nel Regno d'Italia*. Pirotta, Milano, 48 pp.

Amoretti, C. 1811. *Della ricerca del carbon fossile, sui vantaggi ed uso nel Regno d'Italia*. Bernardoni, Milano, 50 pp.

Arecco D. 2003. *Mongolfiere, scienze, e lumi nel tardo Settecento*. Cacucci, Bari, 157-175.

Baillet, C.A. 1803. Sull'incarbonimento della legna e della torba. Osservazioni lette alla conferenza delle Miniere. In: Amoretti, C. (ed.), *Opuscoli Scelti sulle scienze e sulle arti, vol. XXII*. Stamperia di Andrea Majnardi, Milano, 345-357.

BNB (Braidense National Library), Milano, http://www.braidense.it/index/. SALA.FOSC.05 0125/12 "Della ricerca del carbon fossile"; SALA.FOSC.05 0125/13 "Della torba e della lignite".

Candela, A. 2009. *Alle origini della Terra. I vulcani, le Alpi e la Storia della Natura nell'età del viaggio scientifico*. Insubria University Press, Varese, 299 pp.

De Felice, R. 1961. *Dizionario Biografico degli italiani*, 3, 9-10.

De Frenza, L. 2005. *I sonnambuli delle miniere. Amoretti, Fortis, Spallanzani e il dibattito sull'elettrometria organica e minerale in Italia (1790-1816)*. Olschki Editore, Firenze, 257 pp.

Frumento, A. 1991. *Il regno dell'Italia Napoleonico: siderurgia, combustibili, armamenti ed economia (1805-1814)*. Banca Commerciale Italiana, Milano, 973 pp.

Grillo, L. 1846. Carlo Amoretti. In: Grillo, L. (ed.), *Elogi di liguri illustri, seconda edizione, tomo III*. Stabilimento tipografico Fontana, Torino, 148-258.

ILASL (Istituto Lombardo Accademia di Scienze e Lettere), Milano. Fondo Amoretti. Paper 1 "Del Carbon Fossile", Paper 2 "Relazione sul carbon fossile di Cadibona", Paper 3 "Del carbon fossile nelle vicinanze di Como", Paper 4 "Osservazioni fatte in un giro in Valganna e sui laghi di Lugano e Como". In: *File I "Relazione memorie cartografiche carbon fossile e torba", Folder XI (1-18) "Geologia Miniere e Fossili". Folder XVIII "Rabdomanzia". Folder XXIV "Viaggio letterario-scientifico". Box "Miei viaggi" (vol. I-VI and vol. VII-X).*

Labus, G. 1824. Vita di Carlo Amoretti. In: Silvestri, G. (ed.), *Viaggio da Milano ai tre laghi, di Lugano, Maggiore e di Como e né monti che li circondano*. Giovanni Silvestri, sesta edizione, Milano, 9-40.

Maironi da Ponte, G. 1785. Dei Carboni fossili, o Antraci bituminosi di Gandino. Memoria epistolare al sig. Giovanni Arduino. In: Amoretti, C. (ed.), *Opuscoli Scelti sulle scienze e sulle arti, vol. VIII*. Giuseppe Marelli, Milano, 135-139.

Pini, E. 1785. *Della maniera di preparare la torba e di usarla a fuoco più vantaggioso dell'ordinario*. Marelli, Milano, 138 pp.

Singer, C., Holmyard, E.J., Hall, A.R. and Williams, T.I. 1968. La rivoluzione industriale, circa 1750-1850. *Storia della Tecnologia*, 4 (I-II), Boringhieri, Torino, 745 pp.

Torrens, H. 1998. The British "Mineral Engineer" John Williams (1732-1795), his work in Britain from 1749 to 1793 and as a mineral surveyor in the Veneto and North Italy between 1793 and 1795. In: Vaccari, E. (ed.), *Le scienze della terra nel veneto dell'Ottocento*. Istituto veneto di scienze, lettere ed arti, Venezia, 151-199.

Vaccari, E. 2004. The "Council of Mines" and geological research in Italy at the start of the Nineteenth century: research perspectives. In: Vai, G..B. (ed.), *Four centuries of the Word Geology: Ulisse Aldrovandi 1603*. Edizioni Minerva, Bologna, 265-269.

Vaccari, E. 2005. I viaggi mineralogici di Carlo Amoretti in territorio lombardo, tra Settecento e Ottocento. In: Istituto di storia dell'Europa Mediterranea (ed.), *Pratiche e linguaggi, contributi a una storia della cultura tecnica e scientifica*. Edizioni ETS, Pisa, 251-259.

Vaccari, E. 2005. Le istruzioni per i geologi viaggiatori. In: Bossi, M. y Greppi, C.(ed.), *Viaggio e Scienza, le isllustrazioni scientifiche per i viaggiatori nel secolo XVII, XIX*. Olschki Editore, Firenze, 3-25.

Vecchio, B. 1974. *Il bosco negli scrittori italiani del Settecento e dell'età napoleonica*. Einaudi, Torino, 283 pp.

Visconti, A. 1990. Le carte geologiche tra Settecento e Ottocento: dalla rappresentazione descrittiva al documento scientifico. In: Milanesi, M. (ed.) *L'Europa delle carte. Dal XV al XIX secolo, autoritratti di un continente*, Mazzotta, Milano, 62-65.

Visconti, A. 2003. Amministrare il sottosuolo per tutelare il suolo: la grande svolta energetica lombarda tra Settecento e Ottocento. In: Segre, L. y Frey, M. (ed.), *Il sottosuolo lombardo e la gestione sostenibile delle sue risorse*. Bertieri Istituto Grafico, Milano, 59-79.

Visconti, A. 2008. *Il legno brucia: l'energia del fuoco nel mondo naturale e nella storia civile*. Società Italiana di Scienze Naturali, Milano, 99 pp.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

FIELD TRIP GUIDE TO LINARES (JAÉN, SPAIN)

José Dueñas Molina, Antonio José Pérez Ángel, Francisco Molina Molina, José Susi Liébana, Agustín Molina Vega, Manuel Romero Martínez and Daniel Campos López

Colectivo Arrayanes, Linares (Jaén), Spain.
jduenas@ujaen.es

Abstract. Mining activity in the Linares-La Carolina district in Jaen Province, southern Spain, can be traced back four thousand years when the Bronze Age Argaric people mined outcropping veins of copper. Later mining of copper and lead lodes was carried out by the Iberians, Carthaginians and Romans. There are no references to mining during the period of Moorish occupation and the Middle Ages, but records indicate continued mining activity from 1563. Activity increased following involvement of the Spanish Crown in the Arrayanes Mine in 1749. The successful installation of a Cornish pumping engine on Pozo Ancho Mine in 1849 led to a mining boom that transformed the economy of the district. The majority of the mines were equipped with Cornish steam engines and the landscape became dominated by typical Cornish-style engine houses. Many new mines were financed by British capital; others were developed by French, German and Belgian companies. The Spanish Government retained the Arrayanes group of mines, the largest in the Linares district. The last mine closed in 1991 and in the same year the Colectivo Proyecto Arrayanes was formed with the aim of recording, conserving and interpreting the mining heritage of the Linares- La Carolina district.

1. LA TORTILLA MINES: MUSEUM OF MINING EXPLOITATION

These mines were exploited from the beginning of the 19th century by local mining companies as well as by foreign mining companies.

Nonetheless, they had been abandoned until Thomas Sopwith founded the "Spanish Lead Company" in 1864, buying and exploiting these mines. The company was reorganized in 1880 under the name of "T. Sopwith Company Ltd.".

The management of this young and keen English businessman was essential for the good results of the mining activities, as well as of the foundry built in 1874 using updated approaches, resulting in the international respect and recognition of the factories (Fig. 1).

The shafts reached 238 meters of depth in the "San Federico" shaft, and 320 meters of depth in the "Saint Annie" shaft. Both were opened around 1870.

Thomas Sopwith died on July 30th, 1898, in England, due to a tragic hunting accident. The company continued its work, but the complex working process in the deeper level and the huge amount of water made the work impossible from 1901.

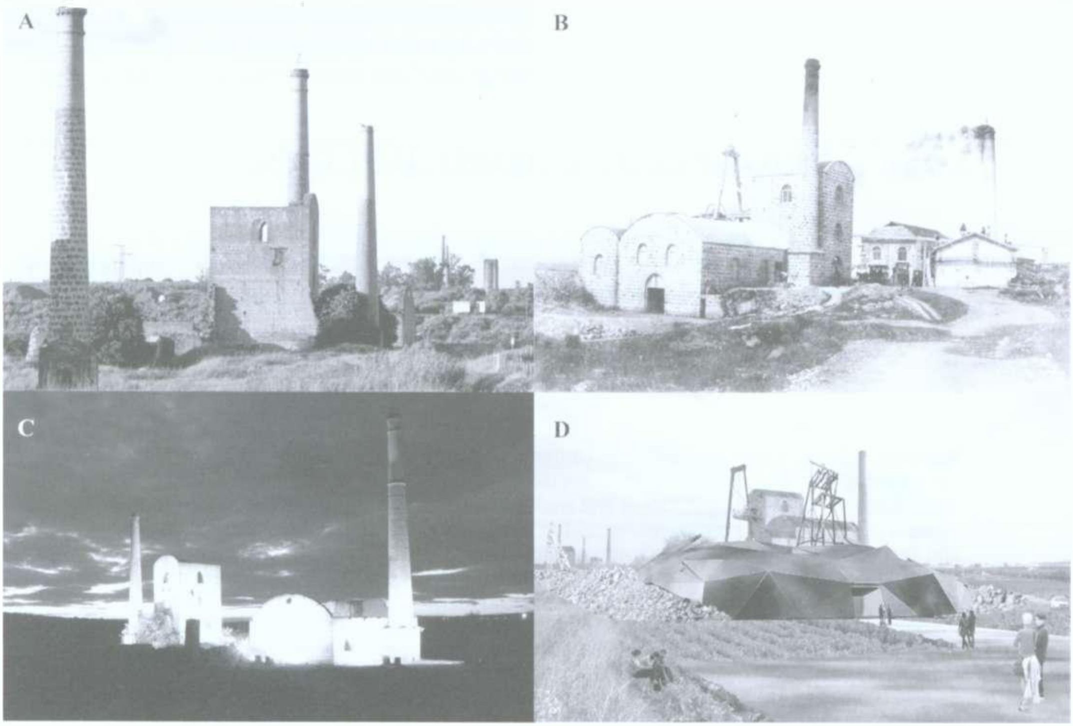


Figure 1. A) View of the facilities at La Tortilla vein; B), El Fin mine in 1904; C) Lighted buildings at San Federico shaft; D) Virtual simulation of the future Visitors Centre in St. Annie shaft

In 1907 the lead extraction in these mines came to an end. Although there were projects and ideas for keeping the mines operating, these projects were finally turned down (Fig. 1).

An area of 22,566 square meters has been bought by the Town Council, and it is intended to build an Interpretation Centre of Cornish technology on these areas, refurbishing the pumping houses of its kind as well as the boiler houses (Fig. 2, 3). It is intended to set up a mining level in order to show the different ways of exploitation, and the access to the level through the "Saint Annie" shaft. All the work carried out by this Museum will be funded by several Departments of the Andalusian government, and the Town Council is looking for collaboration from the Spanish Ministry of Public Works. It is possible to visit the Museum during its construction. The lighting system in the mines was added in 2003.

2. "LA TORTILLA" FOUNDRY, FROM 1974 TO 1967

The foundry began its operations in 1875, using three ovens and smelting 3,000 tons of mineral, obtaining 2,100 tons of lead (Fig. 4). The foundry was continually modernized.

After Thomas Sopwith's death, the company was directed by his son, Thomas, who changed the name of the company to "Thomas Sopwith & C° Ltd.". The new company carried out a huge modernization task, turn-

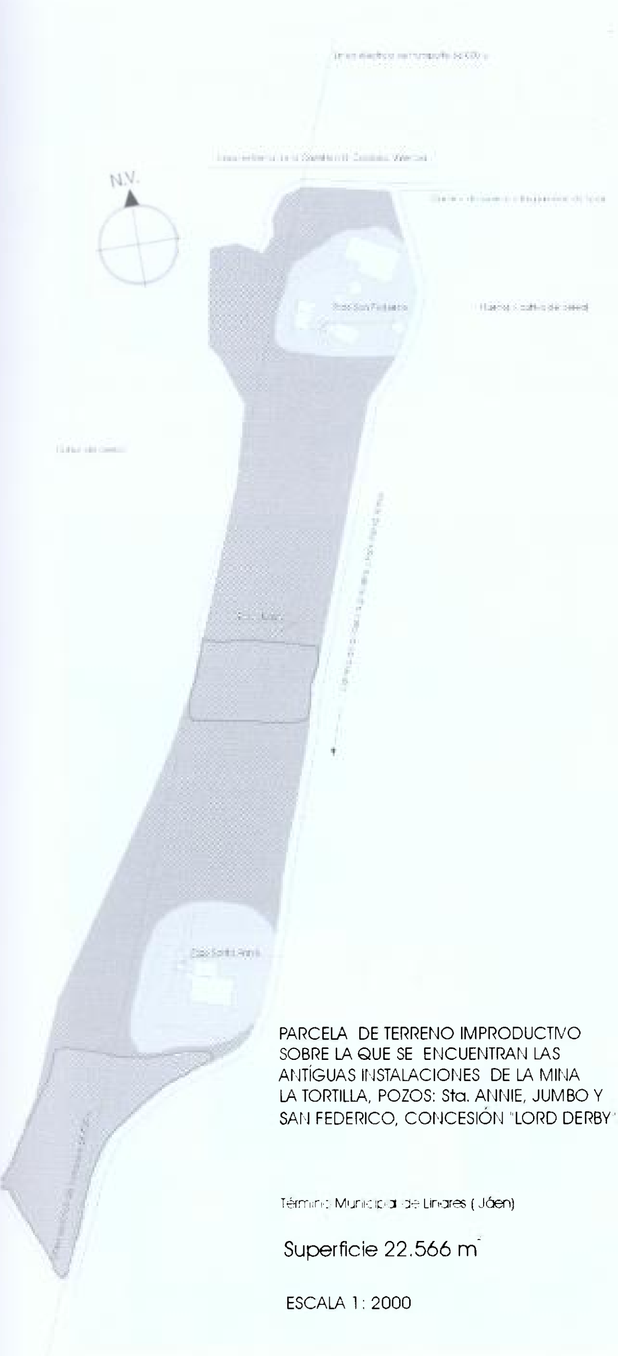


Figure 2. Scheme of La Tortilla mines area.

ing the company into one of the most advanced companies of Europe. In 1885 the new foundry was inaugurated, and the whole range of products which derived from lead was produced.

In 1910 there were 24 Scottish ovens and 12 boilers of Pattinson type for desilvering. The production amounted to 24, 494 tons of soft lead and 14, 302 kilos of fine silver. The whole production was exported to foreign countries.

In 1917 the "Sociedad Minero Metalúrgica de Peñarroya" took over the foundry. In 1940 the converters of "Savelsberg" type had disappeared, and the blast furnace and the desilvering boilers were sent to Morocco.

The foundry definitely stopped its production in 1967. Nowadays, the foundry is very well preserved, especially all the buildings where lead was transformed, as well as the shot tower, which, as a whole, turns out to be a very nice set of buildings. It belongs to the Andalusian Heritage since 2002 (Fig. 5). There are plans to install the Industrial Archaeological Centre of Andalusia in the foundry (Fig. 6).

3. SAN MIGUEL MINES, CIA. MINERA DE LINARES

3.1 San Vicente Shaft

This shaft is located in the San Miguel concession, registered in 1843. San Vicente was the most important shaft of the vein and the main works to drain the mine were concentrated here. There was a Cornish steam pumping engine with a 60" cylinder supplied by five boilers installed here since 1872. The pumping engine house was modified later for the use of electric power. Under the management of Mr. Remfry, in 1880, this mine was considered as a model of the mining facilities in the district (Fig. 7).

In 1890 the San Miguel Mine joined the works over the San José vein, and in 1918 the Linares Mining Company was established to develop the mining works in the area.

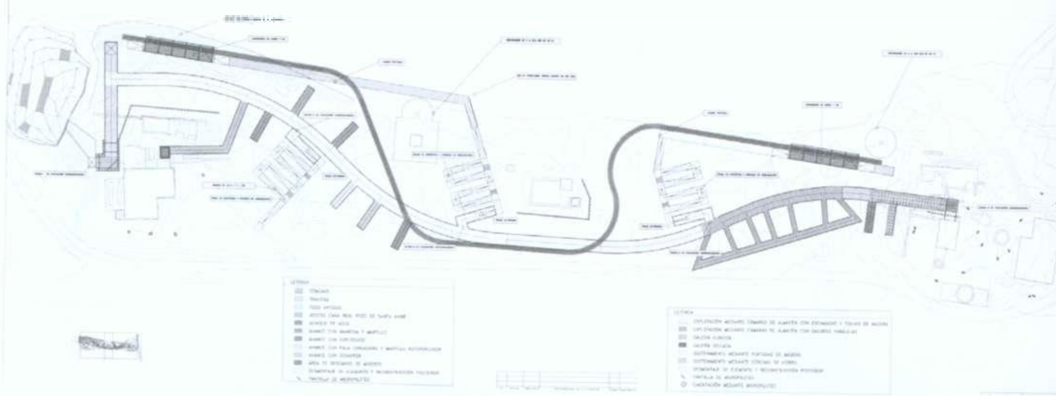


Figure 3. Project for Visitors Centre and Mine in La Tortilla.

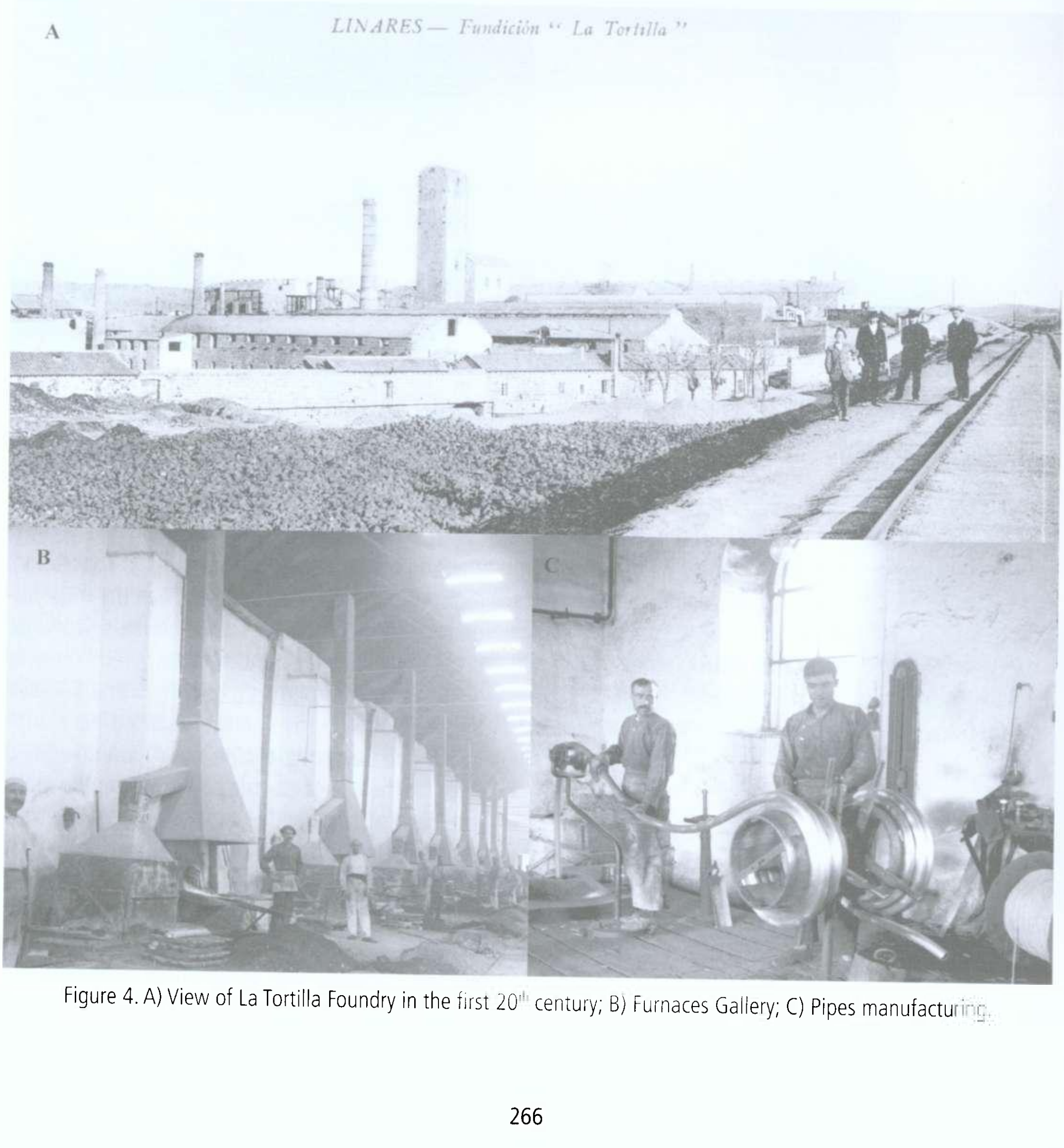


Figure 4. A) View of La Tortilla Foundry in the first 20th century; B) Furnaces Gallery; C) Pipes manufacturing.

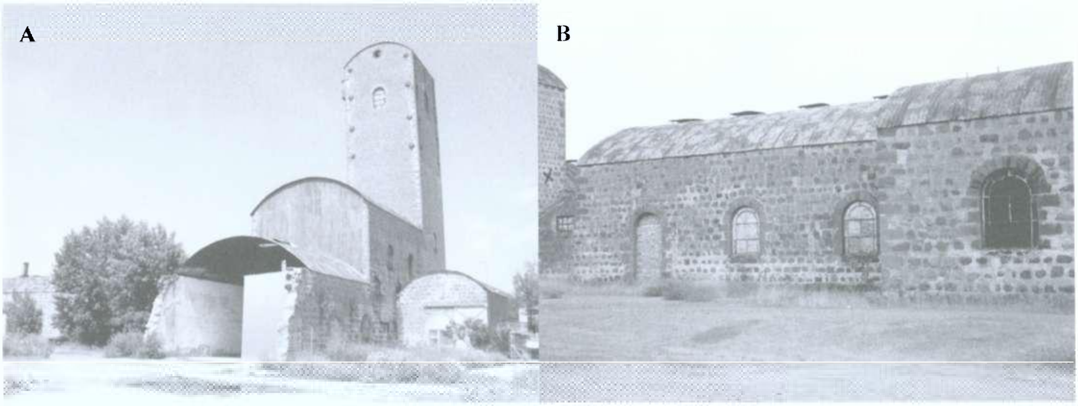


Figure 5. A) Warehouses in La Tortilla Foundry; B) Shots tower and munitions manufacturing facilities.

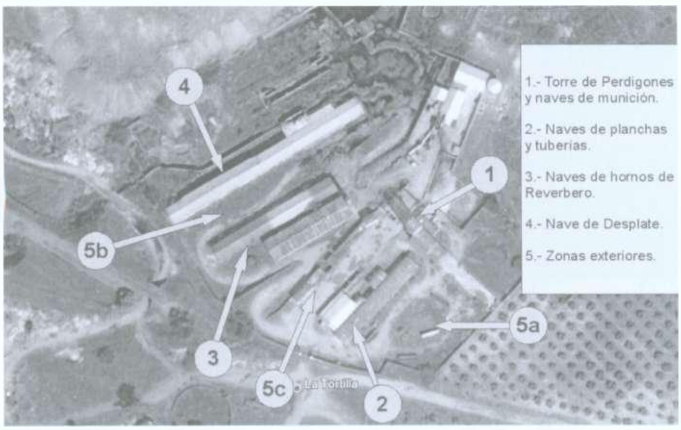


Figure 6. Aerial view of La Tortilla Foundry facilities.

San Vicente was the scenario of a tragic accident occurred in March 1967-one of the last years the mine was opened. Six miners felt down the shaft when they were returning to the surface after they had collected some equipment from the galleries when the mine was about to be closed. This was an emotional shock for the town and the mining sector, and determined the end of activities in this mine.

We believe this site could be an excellent scene for cultural and educational activities, as it has become a real icon for the mining identity of the population of Linares. The Town Council is considering some town–planning measures to obtain the property of the site in a near future.

4. "LA CRUZ" FOUNDRY. METALLURGICAL MUSEUM

The foundry "La Cruz" (Fig. 8) was established in 1830 by Gaspar de Remisa y Mialons, who, as director of the Royal Treasure, was aware of the importance of the seams. He was dedicated to the exploitation and smelting of copper minerals in the region.

Some years later, the French companies "Purcet y Cia., Brissacy Cia., and Adam H. Pache y Cia." took over the company, and in 1863 the French family "Neufville" was in charge until 1949, when the company was sold to the "Central y Santander" bank for 50 million under the name of "Compañía La Cruz, Minas y Fundiciones de Plomo" ("La Cruz Company, Mines and Lead Foundry"). This bank modernized and enlarged the mines and the foundry sector.

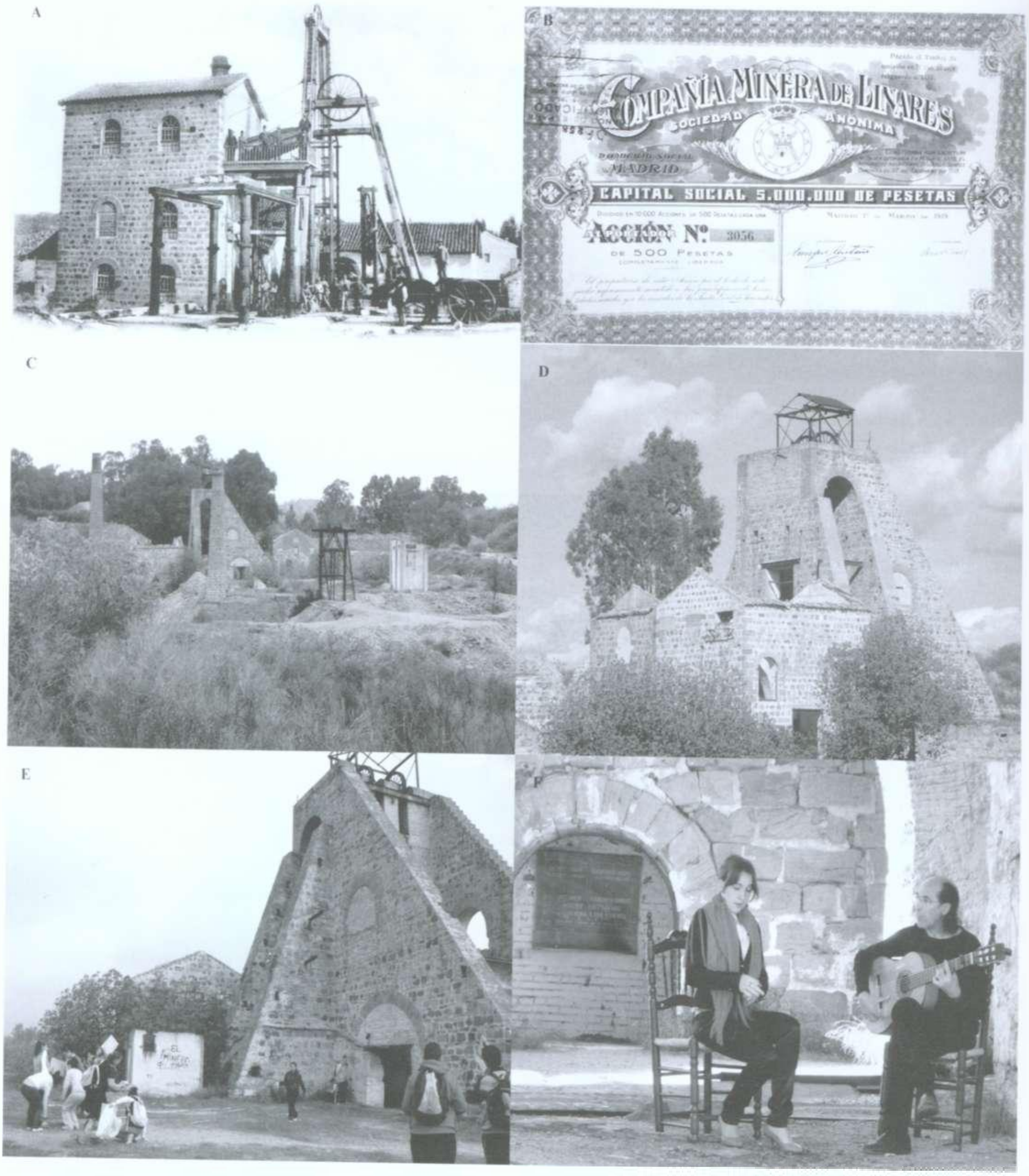
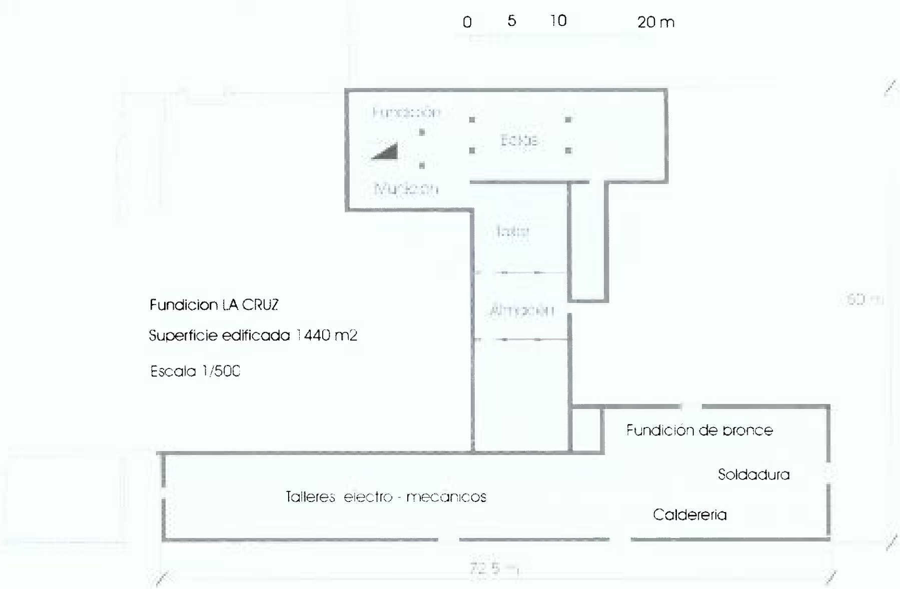


Figure 7. A) S. Vicente shaft in the first 20th century. B) Share of Minera de Linares Company; C) View of the shafts Rico and San Vicente in San Miguel Mine; D) Stone headgear at San Vicente shaft; E) Educational activities at San Vicente shaft; F) Flamenco recital at San Vicente shaft.

Figure 8. A) Opening plaque of La Cruz Foundry; b) Shots tower at La Cruz.

Figure 9. View of the facilities of La Cruz Foundry around 1960.

Figure 10. Facilities that will be restored in La Cruz Foundry.



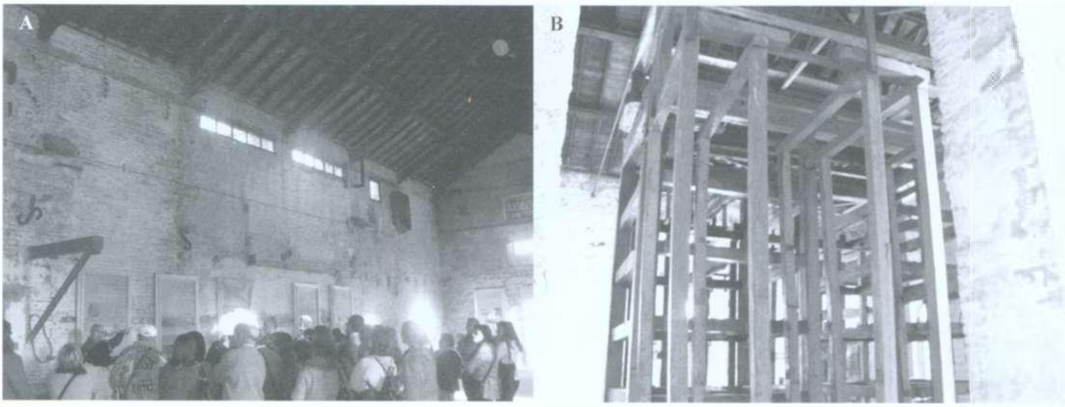


Figure 11. A) Guided visit in munitions warehouse; B) Munitions classifier.

In 1974 the company was split in two different companies: "Minas de la Cruz S.A." on the one hand, and "Compañía La Cruz S.A." on the other hand.

The foundry was modernized in 1975 and this task was finished in 1977-the old way of working was definitely abandoned by then. Five important companies of the mining sector were involved in this modernization project, holding each a 20 percent of the capital: *Compañía Minero-Metalúrgica Los Guindos., Empresa nacional Adaro de investigaciones mineras., Minas de La Cruz S.A., Real Compañía Asturiana de Minas, S.A., and Sociedad Minera y Metalúrgica de Peñarroya-España.*

Due to modernization, the company's production capacity reached 40, 000 tons of lead per year. There were 305 workers, including engineers, administrative staff and workers (Fig. 9).

After some years of production decline, due to the closure of some mines in the area, it was necessary to process mineral from Morocco. The foundry closed in 1986; meanwhile the mine "La Cruz" still extracted its minerals until 1991 (Fig. 10).

4.1 Museum

This place, comprising two halls and a shot tower, has been properly prepared in cooperation with the "Escuela Taller Industria y Paisaje" (Workshop for Industry and Landscape). The Museum will display information about the metallurgical process and recreate a munition factory (Fig. 11).

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources.* Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

A HISTORY OF EARLY COPPER EXPLORATION IN KATANGA (D.R. CONGO)

Eric Pirard

Université de Liège, GeMMe, Sart Tilman B52 4000 Liège, Belgium.
eric.pirard@ulg.ac.be

Abstract. Katanga is a world-class province of sedimentary copper-cobalt deposits that largely contributed to the welfare of the Belgian colony and later to the development of the Congo state. Despite the fact that copper occurrences were known from trading sources as early as the XVIth century, it is only at the very beginning of the XXth century that the potential of the copper ore reserves was clearly established. Although being one of his exploration targets, Katanga was never reached by Livingstone himself. But, very soon after his death, a series of explorations led to the first geological reconnaissance of the region. Despite an almost exclusive focus on gold exploration with the aim to sustain the ambitious Cape-to-Cairo railway project of Sir Cecil Rhodes, a systematic exploration for copper was initiated by the Comité Spécial du Katanga. A few enthusiastic and enterprising Belgian mining engineers very soon saw the opportunity to develop an intense industrial activity at a time when the electricity revolution was requiring more and more copper resources. Despite tremendous challenges in terms of infrastructure and technology this sparked the development of a world class player in the copper business under the name of Union Minière du Haut Katanga.

1. INTRODUCTION

The latest archeological findings suggest that malachite outcrops have been mined as early as the Vth century A.C. in Garanganze a province known nowadays as Katanga (Bisson, 1982). The pre-Bayeke tribes used to seasonally mine these outcrops and cast copper handas (crosses) that were used as exchange good and have been found all over the African continent even reaching Europe as early as XVIth through trade with the Portuguese and the Dutch Oud West Indisch Compagnie. The first explicit mention of copper in European texts is said to date back to March 22nd 1798 in a report made by *pombeiros (afro-portuguese metis)* to the hence governor of Rios de Sena (Mozambique) Francesco Jose Maria Lacerda (Verbeken and Walraet, 1954).

Katanga has long remained as the most inaccessible region of the African continent and still in 1878 Thomson, a famous explorer and Scottish geologist claimed that it would remain for long out of reach. Five years before, David Livingstone had died in Chitambo South of the Bangweulu swamps only a few kilometers away from the modern border of DR Congo. Livingstone had mentioned the existence of copper trading in this region in his accounts from 1854 and 1861. Another famous explorer to mention the mineral wealth of Katanga without being able to come closer is Cameron in 1874.

Figure 1. Portrait of Jules Cornet ca. 1900.

2. PRECOLONIAL MINES REVISITED

2.1 First visits to indigene mine workings

The german expedition of Reichard in 1883 is considered to be the very first to really penetrate Katanga, reaching Bunkeya, the residence of the most powerful autochtonous chief of the time: M'Siri. Reichard plots two copper mines he visited in 1884 on his map: Djola and Kamare (Kamwali). The same year, another expedition headed by the Portuguese officer Ivens accompanied by Capello also mentioned the mine site of Kandumba (close to Kamare). However no geological field observation was available at the time.

A series of Belgian expeditions were set up in 1890 to explore the region and obtain the alledgeance of M'Siri. One of the most successful ones was directed by A. Delcommune and included a young mining engineer named Norbert Diderrich, a former student of Professor de La Vallée Poussin at Louvain University. Diderrich later became the director of agriculture and industry for the Independent State of Congo. He made only a very brief account of his observations (Diderrich, 1893), but a quote from the personal notebook of his companion Dr Briart (Ryelandt, 2004) is more than eloquent about the disappointment of the whole expedition concerning the mineral wealth of the region:

« *Lundi 23 novembre 1890 - Nous nous arrêtons à Katanga afin que Diderrich puisse aller voir les mines de cuivre qui se trouvent à quelques heures de marche. Que nous sommes loin de ce pays d'Ophir dont parle Wauters et dont on a plein la bouche en Belgique depuis quelques années! Il y a du cuivre sans doute, mais l'or!!! Il n'y a que Diderrich qui ait une pièce d'or dans tout le Katanga. Pour le reste néant, nous avons été obligés dernièrement, pour cuire des champignons de les essayer avec de l'argent, en prenant un stylet d'argent de ma trousse de médecin. Quel pauvre pays et quels pauvres gens!* »

One should add that the region was suffering from an intense famine in the times of the Delcommune expedition which certainly adds to the dramatic impression made on the explorers.

At about the same time, another expedition was crossing the region under the lead of captain Bia and lieutenant Francqui. At the explicit request of King Leopold II, a young geologist recently graduated from the University of Gent had been added to the team a few days before leaving Antwerp on May 18th 1891: his name was Jules Cornet (Fig. 1).

2.2 First and second visit to Kambobe by Cornet

Under very harsh conditions and with only very limited time and means, Cornet took extremely valuable notes in a series of eleven notebooks (Cornet, 1892) later synthesized in several important publications that earned him the title of father of Congolese Geology. Gifted with an excellent "*coup d'oeil géologique*" (geological look),

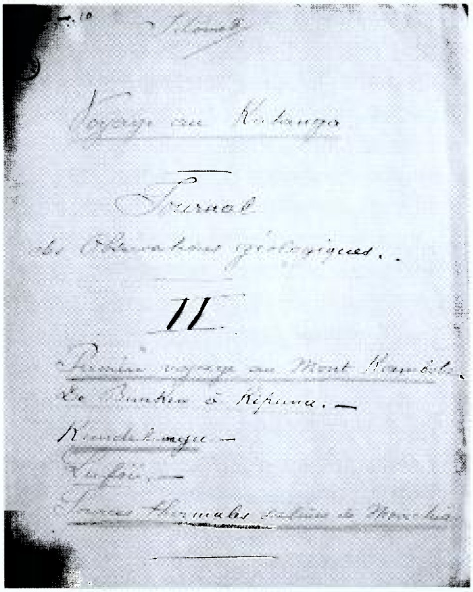


Figure 2. Frontpage of the second field notebook written by Cornet relating his first visit to Mt Kambobe.

he laid down the first definitions of units (Mwashia, Kundelungu, ...) that are still in use today and managed to get a good idea of the geological structure of Katanga.

Cornet arrived in Bunkeya on January 30th 1892, just a month after the local chief M'Siri had been killed by a Belgian officer under unclear circumstances of supposed self-defense. Having heard tales about the existence of gold in the region, he asked indigenes to guide him to the site of "Mount Kambobe" (Kambove) which he visited for the first time on February 17th 1892 (Fig. 2). During his first visit he could hardly make any observation and not even confirm the existence of gold in the Kabambankola river because of the abundance of water at that period of the year. On February 24th an old indigene called Moto brings him back a piece of a sandy clayey rock containing rounded malachite fragments from the same place and claims that it does contain gold. Cornet simply writes "*Conte de gâteux!*" (Senile tale!).
A second opportunity to visit Kambobe and a whole series of other mine workings was given to him from August 8th to September 12th 1892. From the sketch map he draws in his notebook it is obvious that indigenous workings were quite abundant in Kambobe. Cornet no-

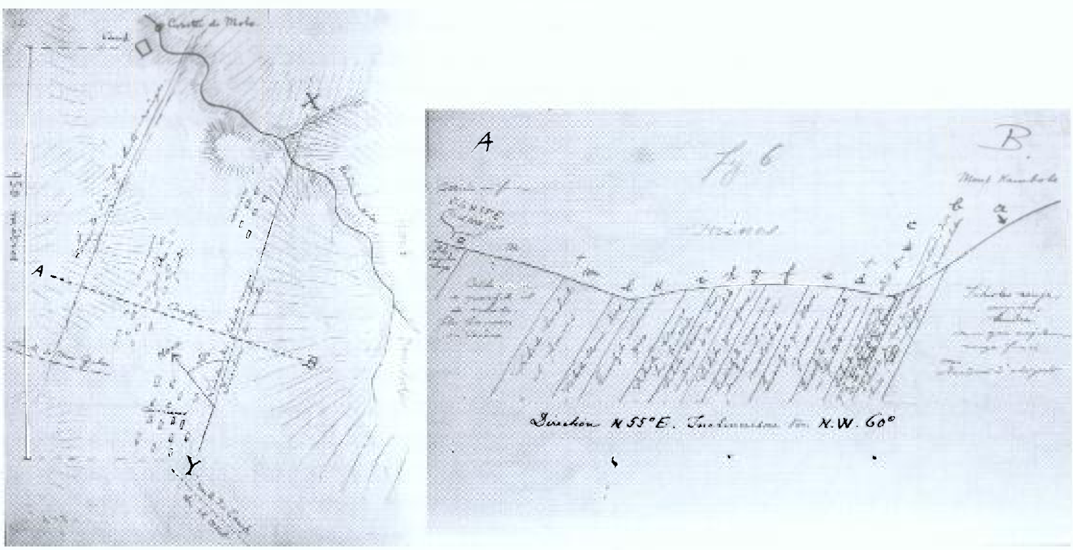


Figure 3. Plan of the old mine workings at Mount Kambobe (hand-drawn by Cornet in his field notebook on 13 Aug 1892) with indication of river Kabambankola and Moto's trough. Limits of mineralisation marked by red schists beds are clearly indicated and detailed in the corresponding A-B cross section.

Figure 4. Artisanal mining by indigenes as pictured by Sharp in Dikuluwe in 1907 (Sharp, 1956).

tes that several pits are 10 to 15m deep and have diameters of about 1.5m to 1.8m. The amount of tailings around the site is described as *enormous*, but no mineral processing installations are visible.

The geological cross section drawn by Cornet on August 13th 1892 (Fig. 3), clearly shows that the mineralization is stratabound and unexistant in the so-called red schists of Moa Guba on both sides of the mineralized sequence. Cornet notes that malachite together with quartz impregnates the sediments and fills in the pores. He suspects the copper hosting rocks to be of the same nature as the red schist but to have suffered from a posterior alteration marked by the presence of talc "?" (with a question mark because he has obviously no instrument to confirm this observation, but the presence of talc is indeed a noticeable feature in these ores).

A few days later, on 25th of August, when visiting the mine of Kiola, he writes: «*...Remplissage de malachite ordinairement plus ou moins parallèle aux bancs. Il y a aussi du minerai dans les interstices. La roche est souvent bréchoïde.*» *and further «...j'ai trouvé un fragment de chalcopyrite, presque entièrement transformé en malachite et limonite ».*

This observation of chalcopyrite is quite exceptional and relatively unnoticed in Cornet's description. He does not suspect at this point that extensive sulphide mineralisations might extend in depth.

All the copper occurrences he visited during those days are listed in his reference publication on metal bearing deposits (Cornet, 1894) together with geological sketches: Lusuichi (= Luiswishi); Kimbui and Inambuloa (the Kandumba and Kamare mines already mentioned by Ivens and Reichard); Kioabana; Kiola (the Djola mine of Reichard); Mont Kitulu; Mont Kambobe (= Kambove); Kamaia; Kalabi (previously visited by Ivens); Miambo (mentioned by the English missionaries Arnot and Crawford in 1893).

Figure 5. Map of the concessions (white squares) attributed to the Compagnie du Katanga by the Independent State of Congo as attached to the 12 march 1891 convention (after du Trieu de Terdonck, 1956).

Cornet readily understood that all his observations were related to similar mineralizing events impregnating sedimentary rocks from the Mwashia group. He also remarks that the mineralized beds are rather easy to locate because they correspond to denuded hills in the landscape. He interprets this as being due to a less fertile soil because of copper contamination.

Cornet makes more explicit comments

about the Luishia deposit, considering it as a good reference site. He also mentions that the indigenous works are very basic, consisting in the extraction of the most accessible block of malachite with pits and trenches of only a few meters extension (Fig. 4). His impression is that, despite their relative importance, most works appear to have been abandoned since several years. The only mine that is described as in operation during that period is the one of Miambo owned by the Balubas.

Cornet has probably been overly pessimistic in his 1892 report when stating that "the relatively low grade of the ores and their remoteness discard for the moment being any idea of exploitation". It is said that this conclusion has been inspired by King Leopold II himself who did not want other nations to cast covetous looks at Katanga. However, one should keep in mind that in 1892 prospectors were looking for gold and the demand for copper was still very low, with only 300 000 tons per year against four times more only twenty years later and fifty times more a century later!

3. SYSTEMATIC EXPLORATION

The Compagnie du Katanga who organized the Bia-Francqui expedition, was operating on behalf of the Independent State of Congo with the responsibility to explore the Upper Congo river basin. The same Compagnie du Katanga had been given in March 1891 mining rights for 99 years (until 1990!) over one third of Katanga territory. In total 4600 blocks of 6' latitude and longitude (12500 ha) forming an incredible chessboard (Fig. 5). This inextricable geometry paralyzed any effort to systematically explore the mineral resources of Katanga for years. It was impossible for any prospector to know whether he was on a block of the Compagnie or on one of the two blocks earned by the Independent State of Congo! It is not before June 19th 1900 that the situation evolved, with the Comité Spécial du Katanga (CSK) being created to manage the interest of both the Compagnie du Katanga and the Independent State of Congo.

At about the same time, a Scottish engineer named Robert Williams was actively exploring Northern Rhodesia in search for mineral resources that could help develop the Cape to Cairo railway project promoted by Sir Cecil Rhodes. In November 1897, the railway track had reached Bulawayo (Zimbabwe), but the future of its tracing through the African continent was still unclear.

Robert Williams entered into negotiations with King Leopold II and the CSK to secure exclusive prospecting rights North of the Congo-Zambezi divide line. He signed a first agreement on December 9th 1900 for a period of five years. One year later, all operations were taken over by the Tanganyika Concessions Ltd (TCL) at shared costs with the CSK. The agreement stated that possible benefits from future mining operations would be distributed between CSK for 60% and TCL for the other 40%.

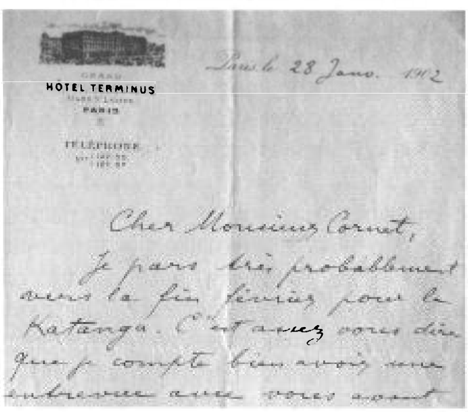
Although the State of Congo was often considered in Belgium as an expensive whim of the king himself, the signature of an agreement with a British company to further explore the mineral resources of Katanga was severely criticized. As claimed a few years later: *"Notwithstanding the excellent engineers and geologists found in Belgium, there is a cruel lack for field prospectors having twenty years experience in the most remote places of the planet, used to travel for months without a bed and even a tent, living on a shoestring… and not even aspiring to be able to see their motherland back one day"* (Büttgenbach, 1906). It is interesting to note that, on the insistence of Prof. Max Lohest, the University of Liege created that same year 1900-1901 a new academic title of Ingénieur Géologue, a world première to be followed later in 1908 by the school of Nancy and many others. The idea behind this new diploma being to educate young engineers with a strong background in geology to bridge the gap between, production (mining) and traditional geology. The initial motivation came of course from the Belgian coal mines, but one might think that the rising interest for Congo was an additional incentive.

3.1 Geologists of the Tanganyika Concessions Ltd.

TCL had been founded in 1899 to explore Northern Rhodesia and one of their geologists, George Grey, had already been successful in locating the Kansanshi deposit a few kilometers to the South of the Congo-Zambezi divide line. During the summer of 1901, a permanent camp with eighteen geologists and prospectors was set up in Kansanshi to support systematic exploration of the region. An analytical lab was also installed under the responsibility of a young geologist named Franz-Eduard Studt who joined TCL in August 1901 and was to remain in Katanga until 1913. The group was divided in two teams of prospectors who were sent out under the lead of George Grey South of the Congo border and John Michael Holland North of it. Even though they were focusing all their efforts on gold exploration, their first campaign allowed them to map numerous copper indices among which many had already been visited by Cornet and were well known from local indigenes. During the dry season of 1901, pits, trenches and galleries are dug at several places such as in Kambove, Msesa, Shituru and Kakanda (du Trieu de Terdonck, 1956) and the first analytical results from systematic sampling are published by Studt in his report to TCL (Table 1).

Copper	14.00
Silica	52.00
Alumina	17.00
F, Ca, Mn, Mg	5.80
CO_2, H_2O	11.20
	100 %

Table 1. Average of ten analyses of selected copper ore samples as published by Studt et al. (1908).


GRAND HÔTEL TERMINUS
PARIS

Paris le 28 Janv. 1902

Cher Monsieur Cornet,
Je pars très probablement vers la fin février pour le Katanga. C'est assez vous dire que je compte bien avoir une entrevue avec vous avant

Figure 6. Büttgenbach's letter to Cornet dated January 28th 1902 announcing his upcoming trip to Katanga (Archives Museum for Central Africa Tervuren).

3.2 Büttgenbach's mission for CSK

In the meanwhile, both TCL and CSK had decided to send over two engineers with the mission to verify the discoveries and establish a first estimate of possible resources. The chief engineer F.R. Farrell arrived in Kambove on July 17th 1902 and stayed there until september accompanied by F.-E. Studt and G. Grey. In his report to TCL he mentions that further prospection should be done but that no economic viability of the operations can be envisioned unless the railway reaches the mine sites.

The CSK mission is conducted by a young mining engineer from the University of Liege named Henri Büttgenbach. Aged only 27, he had already traveled to remote places such as Mexico, Sumatra, Chile or Argentina and published several interesting notes on mineralogy and mineral deposits (Melon, 1964).

Büttgenbach wrote a first letter to Cornet on January 28^{th} 1902 announcing his future mission (Fig. 6). He first arrives in Kambove on June 16^{th} 1902 confusing the malachite cliffs of the far horizon with the green tents of a prospector's camp! In a series of letters written to Cornet in June and October 1903, he mentions his enthusiasm about the results of systematic exploration achieved by Grey's team. At the end of his mission, 52 occurences are already identified and exploration work at Kambove reaches a depth of almost 30m, while being still in the oxidized zone!

Büttgenbach sends systematic reports to the CSK representative in Lukonzolwa (by Lake Mweru). Among these appears the first description of Fungurume, a site that is still a major target for exploration and investments in 2010 (Tenke Fungurume, 2010). He also clearly mentions with foresight that the outcrops are most probably the result of supergene oxidization and that one should expect a progressive transition towards sulfide mineralization in depth. Indeed, rare chalcopyrite remnants are regularly observed in samples from Luishia.

For what about the importance of copper resources, Büttgenbach prefers to remain silent for fear of being accused of exaggeration. Internal reports mention 1,5Mt Cu, but in a later publication (Büttgenbach, 1904) he will mention a minimum of 6Mt of Cu from the sole outcrop data and at least 15 Mt Cu taking into account preliminary results from the exploration drillings. At that time 15 Mt was enough to feed the whole world industry for almost twenty years!

4. FURTHER EXPLORATION AND CREATION OF THE UNION MINIERE DU HAUT KATANGA

4.1 Gold, diamond and tin before copper

Despite these already impressive results, one should realize that the main focus was still put on gold. Every occurrence of copper ore was carefully washed and analyzed for gold and almost every daily report of prospectors mentioned "colours of gold" as the result of systematic prospections in alluvial terrains or around old mine workings. Figure 7 shows a typical drawing attached to a CSK report written by F.-E. Studt in 1906 to illustrate the presence of visible gold in Musonoï. In 1902, a rough estimation by Büttgenbach, indicated that the sole Kambove deposit could contain a minimum of 12 kg of gold. But, after intensive exploration that same year, this number could not be increased and disappointment was gaining ground (Fig. 8). Therefore, in order to foster the discovery of gold occurrences, TCL decided to hire the services of a prospector with former experience in Australia. Herbert George Robins was recruited in 1903 and immediately sent to the Lualaba further north where granite outcrops had been identified by Büttgenbach and it was not long until he discovered together with prospectors Jocks and Cookson the first occurrences of cassiterite in Busanga as well as the first diamond in Mutendele (December 1903). But, the most successful discovery of that year 1903 was the Ruwe gold platinum deposit considered to be extremely promising and almost immediately operated by a work force of two Europeans and hundred fifty indigenes. In six months time, between April and September 1904, they produced 2316

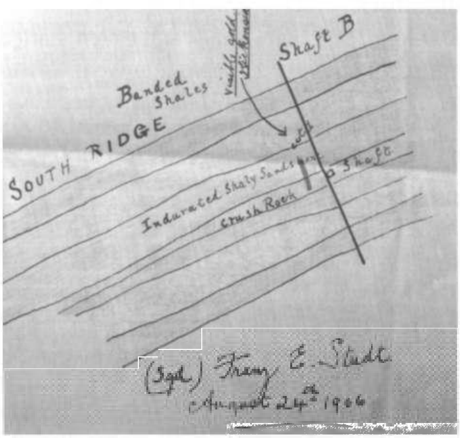


Figure 7. Gold bearing ridge on Musonoï mine by F. E Studt August 24^{th} 1906. (Archives Museum for Central Africa Tervuren G 198/13).

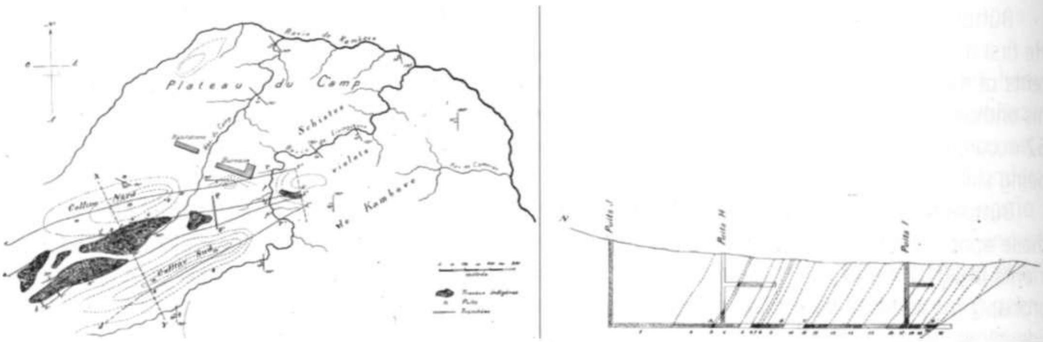


Figure 8. Map of the Kambove prospection site with exploration pits and galleries as published in Studt et al. (1908).

ounces of gold from the eluvial deposit under the direction of Charles Grey (brother of George Grey). This performance motivated TCL to further explore the region and consider transferring their base camp to Ruwe (a transfer which will be effective only in 1906) (du Trieu de Terdonck, 1956). In those early days, George Grey was considered to be the only man in Katanga to be residing in a brick house. Most of the prospectors under his rule were living in tents, itinerating from place to place and surviving in a rather frugal environment. From the memoirs of the future Major E. Sharp (Sharp, 1956) we know that with the exception of a few bottles of whisky, the monthly staffing of a prospector consisted in 20 lbs of flour; 7 lbs of sugar; 3 lbs of jam; 2 mbs of butter together with salt, onions and vinegar (Fig. 9). The missing fat was to be obtained by shooting hippos!

Among the twenty to thirty Europeans actively prospecting a region of more than 100.000 km², English geologist and prospectors were clearly the dominant workforce throughout the period 1901-1910. As an example, internal reports from Lukonzolwa dated between May and July 1908 indicate the presence among others of Chennells J.A; Hulbert J.H. (just arrived in may 1908); Leech Frank; Nesbitt A. T. (on leave); Robins H. G.; Newman Smith H.; Duke L.H. and Rademeyer J. J. Only this last one was probably of Belgian origin as were Manfroy and Lancsweert, two young geologists, sent respectively in 1905 and 1906 to pursue the initial work done by Büttgenbach.

Figure 9. Alan Gibb (head resident mining adviser), Duncan, Sharp (right) and Studt (rear right) at Star of the Congo mine (Sharp, 1956).

It is not before 1905 that a small settlement started to grow on a spot chosen by E. Sharp into what was to become later the city of Lubumbashi (initially named Elisabethville after the Belgian queen Elisabeth).

4.1 First publications

With the exception of Cornet and Büttgenbach who wrote a series of early papers to share their field experience in Katanga, the first scientific contribution of major importance is a geological map of Katanga published in 1908 together with three chapters written by Studt for the explanatory notice of the geological map, Büttgenbach for the mineral deposits and mineralogical aspects and Cornet for tectonics and morphology of Katanga (Studt et al., 1908). This impressive piece of work results more from a juxtaposition rather than a joint cooperation, but it is anyhow the best synthesis of the geological information available at the time (Fig. 10). F.-E. Studt was to publish an updated version of his geological map in a later paper (Studt, 1913) that remained unnoticed for a long time by Belgian geologist as it was published in troubled times and in South Africa.

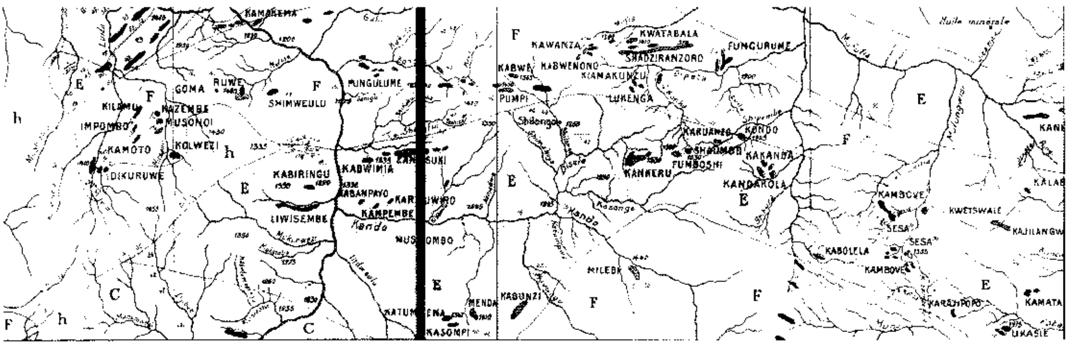


Figure 10. Extract from the geological map published by Studt et al. (1908) between 10°30 S and 11°00 S.

4.2 Belgian engineers and entrepreneurs

Back to Belgium after a quick trip to the Transvaal mines, Büttgenbach began a series of talks at the tribunes of Engineering and Entrepreneurs associations between 1904 and 1906 to advocate the importance of the implication of young Belgian engineers in the exploration and valorization of Katanga's resources. He was intimately convinced of the huge potential of the region and its strategic importance for the future of Belgium's welfare : « *Il existera dans une partie du Congo une industrie métallurgique dont le développement ne fera que croître et qui, par la force des choses, deviendra l'une des plus formidables du monde entier!* » (Büttgenbach, 1906).

It is clear from his correspondence with Cornet, that he very soon had contacts at the highest levels of administration to envisage without delay the creation of a private company to operate future mining and metallurgical operations. This company brought on the baptismal fonts under the name of Union Minière du Haut Katanga (UMHK) on October 28th 1906 is the ancestor of the modern Umicore company (Brion and Moreau, 2006). Henri Büttgenbach became member of the board of the UMHK as representative of the CSK. He served as CEO for five years between 1907 and 1912 and was to remain administrator of UMHK for an uninterrupted mandate of fifty years until 1956!

Despite his strong involvement in the economic development of the colony, Büttgenbach maintained a strong interest for research and teaching. He published over 200 papers and a classical textbook of mineralogy in 1917 "Les minéraux et les roches". In 1921, he succeeded to G. Cesaro as full professor of mineralogy and crystallography at University of Liege until his retirement in 1945. With the exception of 1911 when he came back to Katanga to take part to the first copper fusion, he returned only in 1947 to visit UMHK operations and later in 1950 for the fiftieth anniversary of the CSK congress to act as honorary president of the commission on mining and metallurgy (Thoreau, 1965).

REFERENCES

Bisson, R. 1982. Trade and Tribute. Archaeological Evidence for the Origin of States in South Central Africa. *Cahiers d'études africaines* 22, 87-88.

Brion, R. and Moreau, J.L. 2006. *De la mine à mars - la genèse d'Umicore*. Lannoo, 471 pp.

Büttgenbach, H. 1904. Les gisements de cuivre du Katanga. *Annales de la Société Géologique de Belgique*, XXXI, 515-564.

Büttgenbach, H. 1906. L'avenir industriel de l'état indépendant du Congo. *Revue Universelle des Mines*, 14, 115-147.

Cornet, J. 1892. *A series of eleven field notebooks*. Archives of the Museum for Central Africa, Tervuren (may 2010). (Unpublished)

Cornet, J. 1894. La géologie de la partie Sud-Est du Bassin du Congo et les Gisements Métallifères du Katanga. *Revue Universelle des Mines, de la Métallurgie*, XXVIII, 217-280.

Diderrich, 1893. *Esquisse du Katanga au point de vue géologique*. Mouvement Géographique, 40 pp.

du Trieu de Terdonck, R. 1956. Géologie et recherches minières. In : Robert, M. (ed.), *Géologie et géographie du Katanga*. Imprimerie Hayez, Bruxelles, 620 pp.

Melon, J. 1964. Notice sur Henri Büttgenbach. *Annales Soc. Géol. Belg.*, 125-160.

Tenke Fungurume, 30/07/2010, http://www.fcx.com/operations/africa.htm.

Ryelandt, D. 2004. *Aux sources du fleuve Congo. Carnets du Katanga (1890-1893) de Paul Briart*. L'Harmattan, Paris, 370 pp.

Sharp, R.R. 1956. *En prospection au Katanga il y a cinquante ans*. Imbelco, Elisabethville, 163 pp.

Studt, F.-E., Cornet, J. and Büttgenbach, H.. 1908. *Carte géologique du Katanga et notes descriptives*. Musée du Congo, Bruxelles, 94 pp.

Studt, F.-E. 1913. The geology of Katanga and Northern Rhodesia, an outline of the geology of South Central Africa: Trans. *Geological Society of South Africa*, XVI, 44-102.

Thoreau, J. 1965. Notice sur Henri Büttgenbach, Annuaire de l'Académie, pp. 125-160

Verbeken, A. and Walraet, M. 1954. *La première traversée du Katanga en 1806, Voyage des «Pombeiros» d'Angola aux Rios de Sena*. Bruxelles, IRCB, 133 pp.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

HISTORY OF PROSPECTING, RESEARCH AND EXPLOITATION OF CHROMITE DEPOSITS OF THE URALS AFTER COLLECTIONS OF ACADEMICIAN F.N. TSCHERNYSCHEW CENTRAL RESEARCH GEOLOGICAL PROSPECTING MUSEUM, SAINT-PETERSBURG, RUSSIA

Leonid R. Kolbantsev, Oleg V. Petrov and Aleksei R. Sokolov

A.P.Karpinsky Russian Geological Research Institute (VSEGEI),
Sredny Prospect, 74. 199106 St. Petersburg, Russia.
Leonid_Kolbantsev@vsegei.ru, vsegei@vsegei.ru, Aleksey_Sokolov@vsegei.ru

Abstract. Collections of the F.N. Tschernyschew Central Research Geological Prospecting Museum (CNIGR Museum) illustrate the history of prospecting, research and exploitation of various types of mineral deposits, including chromite deposits of the Urals. Based on the study of collections we can establish 4 stages of research and exploitation of chromite deposits: I (1850-1918), hand-dig mining in Middle and Southern Urals without geological prospecting and investigations of deposits; II (1920-1940), intensive prospecting and investigations of chromite deposits from Northern to Southern Urals and Kazakhstan; III (1946-1991), benefit of priority on investigations of Kempirsay massif chromite deposits (Kazakhstan); IV (after 1991), Polar Urals deposits –the main source of metallurgical chromites in Russia. These stages are characterized by Museum collections, which show the author's viewpoint on genesis and pattern of ores concentration, principles of their prospecting and investigation. Also, collections illustrate the structural variety and features of minerals and the chemical composition of ores.
Short descriptions of the activity carried out by the geologists-authors of the collections are given.

1. THE CNIGR MUSEUM IS THE LARGEST STOREHOUSE OF GEOLOGICAL INFORMATION OF RUSSIA

F.N. Tschernyschew Central Research Geological Prospecting Museum was founded in 1883, along with the organization of the first state geological institution —the Geological Committee of Russia. The main aim of the Museum was "to collect those materials which form the base for geological map compilation and geological description of the territory" (Zhurnal zasedania, 1883). Thus, the Museum became the largest storehouse of geological information.

Now, the Museum collections characterize the geological structure and the mineral deposits of Russia and its adjacent states in 3 main divisions: Regional Geology, Mineral Deposits, and Monographic Paleontology. The collection fund counts with about 1 million specimens of minerals, rocks, ores, and fossils; over 80,000 of them are exposed in the exhibitions, and 352,536 petrography thin sections. In majority, these collections illustrate the geological investigations of the Geological Committee (1882-1929), A.P. Karpinsky Russian Geological Research Institute (VSEGEI), and other state geological organizations of the USSR and Russia.

The collections of the Mineral Deposits division characterize more than 1,300 deposits of 70 kinds of raw materials, according to the mode of their formation and mineral composition of ores and ore-bearing rocks. Specimens have been collected for 127 years and thus are the witnesses of the history of research of various types of deposits. From this point of view, the Urals deposits are extremely interesting, because the Urals was the main mining region of Russia since the 17th century.

On the other hand, the Urals is a unique province for the scale of ultramafic rocks and associated deposits. More than 300 ultramafic massifs and a great number of small bodies are located here. Almost all exploited chromite deposits of Russia are concentrated in the Urals within alpine-type ultramafic rocks and Saranovsky stratiform complex.

2. FOUR STAGES OF RESEARCH AND EXPLOITATION OF CHROMITE DEPOSITS OF THE URALS

Some chromite deposits in the Urals were used for extraction of semiprecious stones (uvarovite, precious serpentine) since the beginning of the 19th century. After 1850 chromite ores became raw materials for chemical and refractory industries. Chromium manufacturing for metallurgy began only in the 1910's.

On the basis of inspection of collections, we can mark out 4 stages of research and exploitation of chromite deposits of the Urals:

I (1850-1918): hand-dig mining in Middle and Southern Urals, without geological prospecting and investigations of deposits;

II (1920-1940): intensive prospecting and investigations of chromite deposits from the Northern to Southern Urals and Kazakhstan;

III (1946-1991): benefit of priority on investigations of Kempirsay massif chromite deposits (Kazakhstan, southern continuation of the Urals structures);

IV (after 1991): Polar Urals deposits-the main source of metallurgical chromites in Russia.

These stages are characterized by Museum collections, which show the authors' viewpoint on genesis and pattern of ores concentration, principles of their prospecting and investigation.

3. THE I STAGE (1850-1918)

The I stage of chromites prospecting and exploration in the Urals was connected with hand-dig mining. It began in the middle of the 19th century by the construction of small private factories. Tens of rich chromite deposits were discovered in the Middle and Southern Urals. In 1870, export of chromites to Europe was organized (7,000 tons p.a.); this caused a "chromite boom" (Lokhtin, 1874).

At the end of the 19th century Russia became a world leader in chromite extraction. In 1901 more than 22 thousand tons were extracted—approximately 47% of the total world output. Mining at that time was carried out by means of pits, open-cast mines, and shallow shafts. Only high-grade ores were extracted, and workings were limited by the level of ground waters or depletion of high-grade ores. Geological prospecting and investigations of deposits were not executed. Ores were used for the purposes of chemical (60%) and refractory (40%) industries (Zavaritsky, 1918).

After 1903, Russian chromites were replaced in the world market by cheap and high-quality ones from New Caledonia, Southern Rhodesia, and Turkey. In 1913 only 15% of the world chromites were extracted in Russia (Zavaritsky, 1918).

Figure 1. Picture of Alexander Shtukenberg (1901).

Figure 2. Picture of Feodosiy Tschernyschew (1912).

During this period, single ultramafic rocks and chromite ores samples were delivered to the Museum as part of collections illustrating the geological map of the European side of Russia. Collections were gathered in 1886-1916 by A. Shtukenberg, A. Zaytsev, F. Tschernyschew, and A. Zavaritsky.

Alexander Shtukenberg (1844-1905) (Fig. 1) was a Professor of Kazan University (1876) and President of the Kazan Society of naturalists (since 1880); one of the greatest experts in geology and paleontology of the Paleozoic of the Urals and Southern Russia at one time. He was one of the first geologists who prepared and taught a course on "The Geology of Russia" (1886).

A. Shtukenberg compiled few sheets of the Geological Map of European Russia (1890, 1898) and transferred some collections to the Museum, including samples of chromite ores (1895).

Feodosiy Tschernyschew (1856-1914) (Fig. 2) was a leading expert in geology and paleontology of the Ural's Paleozoic rocks, an academician of the Russian Academy of Sciences (1899); Director of the Geological Museum of Peter the Great (1900-1914); Director of the Geological Committee of Russia (1903-1914); and Director of the St. Petersburg Mining Institute (1910).

F. Tschernyschew investigated the Northern and Southern Urals (1880-1888), headed the geological surveying in Donets coal-basin (1892-1899), Timan Ridge (1889-1890), Novaya Zemlya (1895), and Spitsbergen (1899-1901, measurements of a meridian arch). He compiled few sheets of the Geological Map of European Russia, participated in the compilation of the International Geologic Maps of Europe and World as a member of the Commission of the International Geological Congress.

F. Tschernyschew made a lot for organization and development of the Museum and brought himself collections of rocks and fossils from different regions, including samples of the ultramafic rocks and chromite ores from the Urals (1889).

Aleksey Zaitsev (1856-1921) (Fig. 3) was a Professor of Kazan (1887), Tomsk (1896), and Warsaw (1909) universities, and of Tomsk Technology Institute (1901); founder of the Siberian Geological School, and organizer of the Geological Museum of the Tomsk University (1888). In 1885-1888 he was engaged in the research of ore deposits in the Middle Urals and brought a collection of chromite and iron ores to the Museum (1886).

The beginning of the WWI had increased chrome requirement for steel production. In 1916 **Vladimir**

Figure 3. Picture of Aleksey Zaitsev.

Figure 4. Picture of Vladimir Voznesensky (1925).

Voznesensky (Fig. 4) was directed by Geological Committee for inspection of chromite deposits in the Urals. He visited more than 200 deposits in the Middle and Southern Urals and gathered a very representative collection—over 800 samples of chromite ores and hosting rocks (Fig. 5). It became the first regular chromite collection of the Museum. Nowadays it is difficult to define the exact location of the samples from this collection, as the records contain old names of mining districts, private mines, pits, etc. Most of them are not preserved in modern toponymy, especially those having ideological or religious nuances (such as names of tsars, saints, mine owners, etc.). In addition, "usually, mines were exhausted in 2-3 years and works were transferred to other deposits of the same area" (Voznesensky, 1921, p. 140).

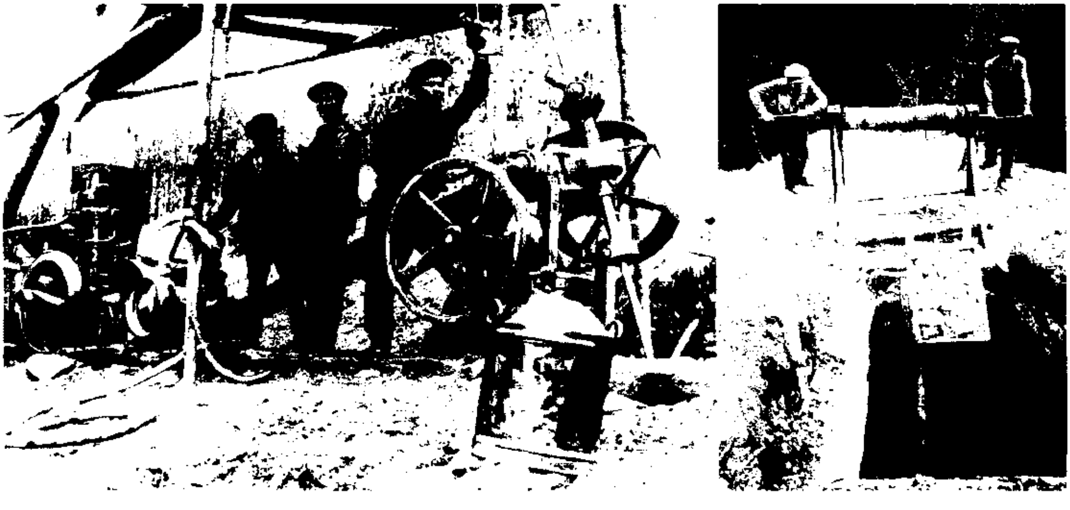


Figure 5. Prospecting works in the Bolshoy Boshart chromite deposit, Kraka massif, the Southern Urals (1935).

Vladimir Voznesensky (1858-1927) was a geologist of the Geological Committee; he was engaged in hydrogeology and water supply of cities in Central Russia and Ukraine. Due to collaboration with revolutionary organizations, he was sent to East Siberia in 1898, where he participated in geological investigations in the area of the Trans-Siberian Railway. Later, he refused to participate in the construction of the Alexander III monument in Irkutsk; he was arrested again and sent to Yakutia (Vysotsky, 1927).

Further, V. Voznesensky studied the Ural's gold, chromite, and asbestos deposits, and also the emerald mines (1916-1927).

4. THE II STAGE (1920-40)

It was connected with the USSR's industrialization epoch. During this period, intensive prospecting for new deposits and investigations of existing deposits took place. At that time, most of the deposits that are known nowadays were discovered.

Such activity ended in 1937, when unique Kempirsay deposits were discovered and works in other regions stopped. Till this time, Kempirsay massif was not mentioned in literature devoted to chromites. In 1936 geologist P. Dolgov found by accident the occurrence of large blocks of chromites. Next year, twenty ore bodies were discovered. And, as early as 1938, the Don mining complex began to work. (Loginov et al., 1940). Now it is still running in Kazakhstan, and is one of the largest chromite mining complexes.

In 1925-40 outstanding Russian geologists were engaged in chromite ores investigations. The collections gathered by A. Karpinsky, A. Zavaritsky, A. Betekhtin, P. Tatarinov, G. Padalka, A. Gejsler, and others, are stored in the Museum. They characterize a lot of massifs, types of ores, enclosing deposits, rocks and minerals. Based on them, the changes of outlooks on ores genesis and the way of their investigations can be traced. Unfortunately, part of these collections was lost during the Leningrad blockade (1941-1944).

Alexander Karpinsky (1846-1936) (Figs. 6 and 7) was a world famous geologist, an academician of the Russian Academy of Sciences, the initiator of some large directions in geological cartography, tectonics, and palaeogeography, and one of the organizers of the Geological Survey of Russia. He was the Director (1885-1903) and Honorary Director (until 1929) of the Geological Committee; first elected President of the Russian Academy of Sciences and the first President of the Academy of Sciences of the USSR (1917-1936); President of the Russian Mineralogical Society (1899-1936), and President of the VII IGC session in 1897 in St-Petersburg. His activity is noted by the awards of many Russian and foreign scientific societies.

Having studied chromite structures, A. Karpinsky offered a hypothesis on explosive chromite ores genesis similar to that of kimberlites (Karpinsky, 1926).

Alexander Zavaritsky (1884-1952) (Fig. 8) was an academician of the Academy of Sciences of the USSR (1939), a Russian geologist, petrologist, and an expert in ore deposits, volcanology, theory of petrography, and ore genesis. He had explored the Ural Mountains at its full extent, from Polar to southern areas, and became the best expert in the petrography and the ore deposits geology of this region. The mineral zavaritskite was named in his honor (1962).

He published numerous works, including classical monographies, where he considered actual problems of physical chemistry and petrochemistry of magmatic rocks, history of the Urals magmatism, and where he described large magmatic complexes and ore deposits in detail. For the first time, the chromite ores in the Ray-Iz massif are noted in his classical monography "The Rai-Iz peridotite massif in the Arctic Ural" (1932).

A. Zavaritsky transferred more than 100 collections to the Museum; many of them demonstrate the structural and compositional features of the ultramafic rocks and the chromite ores.

Figure 6. Picture of Alexander Karpinsky (1932).

Figure 7. The sample was named by Karpinsky "a pebble-like chromite in serpentinite". Now it is named as "nodular ore", and it is considered earliest, primary chromite ore.

Figure 8. Picture of Alexander Zavaritsky in the Urals (1911).

Figure 9. Picture of Anatoly Betekhtin.

Anatoly Betekhtin (1897-1962) (Fig. 9) was an academician of the Academy of Sciences of the USSR (1953), an expert in geology and mineralogy of ore deposits, and the creator of the Russian ore microscopy. In 1924-40 he investigated the platinum, chromite, and manganese deposits of the Urals and Caucasus. The mineral betekhtinite was named in his honor (1955).

A. Betekhtin has produced more than 200 scientific publications, including large classical reference and manual books on Mineralogy and the ore microscopy. Many expert geologists consider "Mineralogy" by A. Betekhtin (1950) as the best reference book on Mineralogy till now.

A. Betekhtin gathered collections during his prospecting works in the Southern Urals chromite deposits in 1935.

Pavel Tatarinov (1895-1976) (Fig. 10) was a corresponding member of the Academy of Sciences of the USSR (1953) and an expert in ore and non-metallic mineral deposits. He was the Chairman of the State Committee on Mineral Reserves (1942-1946), President of the All-Union Mineralogical Society (1962), and one of the authors of the first Russian textbook on non-metallic minerals (1936).

P. Tatarinov was engaged in prospecting and research of chromite deposits; his collections demonstrate a variety of rocks and ores from many ultramafic massifs of the Northern and Southern Urals (1934-1940).

Figure 10. Picture of Pavel Tatarinov (1970).

5. THE III STAGE (1946-1991)

After 1940, the investigators were mainly focused on the chromites of Kempirsay deposits. Geologists studied in detail the structure of the Kempirsay massif and ore bodies, laws of placing of ores, and developed methods for ore searching and investigation.

Structural-textural types of ores, relations with enclosing rocks, and different views on their genesis are characterized in detail by the collections of N. Pavlov and G. Kravchenko -they were very authoritative experts in the geology and deposits of the Kempirsay massif.

The collections from S. Moskaleva and V. Kuznetsova illustrate their original new hypotheses on the origin of ultramafic rocks and chromite ores as result of the Earth mantle processes (1970).

The special Museum expeditions were also carried out at that time (1957-1963, 1972, 1987).

6. THE IV STAGE (AFTER 1991)

In the 1970's and 1990's the interest in the Polar Urals deposits had increased. Prospecting of chromites in the Polar Urals began in 1968 in two largest Ray-Iz and Voykar massifs. Some tens of ore bodies were discovered. Exploitation of the Centralnoye chromite deposit, Ray-Iz massif, started at the end of 1996. Nowadays, more than 400 thousand tons of ore are extracted there p.a. (Gosudarstvenniy doklad…, 2010).

After 1991, Kazakhstan became an independent state and Russia lost those Kempirsay deposits. Thus, the Polar Urals deposits became the main source of metallurgical chromites in Russia.

Collections of ultramafic rocks and chromite ores from the Polar Urals were gathered by A. Savelyev (1972), S. Shcherbakova (1981), N. Lutskina (1972, 1980), L. Gurskaya et al. (1989-1993). These collections illustrate structures of massifs, rocks and ores types and display information on the maintenance of the platinum group metals in them.

7. CONCLUSIONS

As a whole, 38 Museum collections characterize more than 40 Urals chromite-bearing massifs including mined, worked out, abandoned, and unexplored deposits, especially in the Middle and Southern Urals. The author's viewpoint on genesis and pattern of ores concentration, principles of their prospecting and investigation at the same time are fixed in them, because each author collected samples that can confirm or illustrate their hypothesis (magmatic or metasomatic structures, secondary alteration, tectonics control, different forms of ore segregations, and others).

Thus, studying of Museum collections and the information connected with them leads to reconstruction and specification of history of geological researches.

REFERENCES

Karpinsky, A. 1926. O veroyatnom proiskhozhdenii korennyh mestorozhdeniy platyny ural'skogo tipa (About the probable origin of primary platinum deposits of the Urals type). *Bulletin of the Academy of Sciences of the USSR, Series 6,* 20(1-2), 133-170.

Loginov, V., Pavlov N.V. and Sokolov, G.A. 1940. Chromitonosnost' Kempirsayskogo massiva na Uzhnom Urale (Chromite bearing of the Kempirsay massif in the Southern Urals). In: Fersman, A., Betehtin, A. (eds.), *Chromites of the USSR.* Academy of Sciences of the USSR, Moscow, 2 5-197.

Lokhtin, P. 1874. Nastoyashchee polozhenie chromovogo dela v Rossii (Present state of the chromite business in Russia). *Gorniy zhurnal (Mining journal)*, 2 (2-4), 315-361.

Gosudarstvenniy doklad "O sostoyanii I ispol'zovanii mineralno-syryevykh resursov Rossiyskoy Federatsii, 2009 godu" (The state report "*About the conditions and use of mineral resources of the Russian Federation in 2008*"). Mineral, Moskow, 400 pp.

Vysotsky, N. 1927. Vladimir Alexandrovich Voznesensky. Nekrolog (Obituary). *Bulletin of the Geological Committee* 46, (5), 523-527.

Voznesensky, V. 1921. O zalezhah chromistogo zheleznyaka na Urale (About chromic iron-ore deposits in the Urals). *Bulletin of the Geological Committee*, 40, 138-142.

Zavaritsky, A. 1918. Chromium. In: Vernadsky, V.I. (ed.), *Estestvenniye proizvoditelniye sily Rossii (Natural productive forces of Russia).* KEP'S Report, Leningrad, 4 (4), 1-9.

Zavaritsky, A. 1932. *Peridotitoviy massiv Ray-Iz v Polarnom Urale (The Rai-Iz peridotite massif in the Arctic Ural).* GNTGI, Leningrad, 222 pp.

Zhurnal zasedania prisutstvia Geologicheskogo Komiteta 39 yanvarya 1883 (The Minutes of the Geological Committee session 29 January 1883). *Bulletin of the Geological Committee,* 1883, 2 (1), 2.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

ALFRED WILLIAMS AND LEO DAFT: PIONEERS IN GEOPHYSICAL PROSPECTION

Robert Vernon

Colectivo Proyecto Arrayanes, Spain & Welsh Mines Society, UK.
2, Grange Field Road, Bredon, Tewkesbury GL20 7AZ, UK.
rbrtvernon@aol.com

Abstract. The early history of geophysical prospection for minerals is poorly recorded and the names of Alfred Williams and Leo Daft may only get a brief mention in any works on the subject. However, the Daft-Williams system patented in the early 1900s was a method of earth resistance surveying for minerals that employed a system of alternating electric currents and telephone receivers. Although actual records of their surveys are sparse, there are adequate accounts of their surveys on a number of British mine sites. Their techniques were later employed on mine prospects in Ontario in Canada, Linares in Spain, and Australia, and in the latter country the use of their equipment is recognised as the first geophysical survey conducted there. Daft and Williams, both British by birth, spent their early years in the United States of America but later returned to Britain and established what was probably the first geophysical prospecting company in the world. *Williamstow Ltd.* was registered in London in 1900. However, as this name did not reflect the nature of the business, the company was renamed *The Electrical Ore-Finding Company Ltd.* in 1901. Although this company only functioned until late 1905, when it was put into liquidation, it can be regarded as the forerunner of what is today a multi-million pound industry. The achievements of Daft and Williams are revealed by recently discovered information about their surveys.

1. INTRODUCTION

The history of geophysical prospection for minerals really commenced in the first half of the 19th century when Robert Were Fox, more remembered as the discoverer of the geothermal gradient, conducted simple self potential experiments in Cornish metal mines. The advent of telegraphy progressed the technology and fundamental experiments by William Preece, and others showed that electric currents could travel through the ground (Vernon, 2007).

However, the names of Alfred Williams and Leo Daft may only get a brief mention in any historical works on the subject (Sweet, 1978), but by 1900 they had perfected a technique for detecting variations in earth conductivity using an alternating current and a telephone receiver, which they called the "Electrical Ore-Finder" (Vernon, 2009). By 1907 this technique was being used worldwide with limited success.

This paper outlines the technique's history, provides some detail of some recently discovered survey results and questions why this innovation has never been given the recognition it apparently deserved.

2. ALFRED WILLIAMS AND LEO DAFT AND THE ELECTRICAL ORE-FINDING COMPANY LTD.

Leo Daft was born in Birmingham, England, in 1843. After gaining a degree at London University, he went to the USA in 1866. There he is credited with the invention of the third rail system used by electric trains. By 1890 he had moved to Seattle (Vernon, 2008).

Alfred Williams was born in 1871 at Oswestry, England. He went to Seattle, USA, about 1888, where he would eventually marry Leo Daft's oldest daughter Matilda. He obviously got on well with his father-in-law as they started experimenting on earth-resistance prospection and later conducted field trials in Alaska, where the system became known as the "Electrical Ore-Finder" about 1896 (Vernon, 2008).

In 1899, Williams and his family settled in England, where he set up what is believed to be the first geophysical prospection company in the world. Daft was to follow shortly afterwards to help Williams to perfect the system. To achieve this, Williams found two business partners, Edward Kenyon Stow and Herbert Straker and on the 20th July 1900 an agreement was made between Alfred Williams and the company *Williamstow Limited* (derived from a combination of surnames) in which he is recognised as the inventor of the Ore-Finder system. However, the name *Williamstow* didn't really reflect the nature of the business, and so at a meeting held on the 13th December 1901, the company was renamed '*The Electrical Ore-Finding Company Ltd.*' (National Archives, Kew, London, BT31/9016/66700)

3. SURVEY TECHNIQUE AND THE EQUIPMENT

What Daft and Williams were intending to carry out were simple earth resistance surveys, since they were detecting changes in conductivity. The technique involved placing two electrodes into the ground and connecting them to an electrical source. The electric currents flowed through the ground between the two electrodes (transmitting electrodes). In homogeneous strata, lines of equi-potential, measured as voltage, maintain a fairly regular distribution pattern between the electrodes that can be detected by putting two further electrodes (receiving electrodes) into the ground and connecting them to a suitable receiving device, in this case a telephone earphone. A mineral vein for example, can disrupt the flow of the currents completely, or depending on its composition, conduct the electric current. Other geological features, for example faulting may also affect the ground conditions, so interpreting the results can be a very complex process (Anonymous, 1903a; Vernon, 2008).Their field equipment was very simple. The bulkiest item was the battery and the transmitting equipment housed in a wooden box, and the electric motor used to make and break circuits to provide an alternating current. Apparently, a voltage of 30,000 volts with a current of 6 to 7 amps was generated (Anonymous, 1903b). In Figure 1, the transmitting and receiving equipment are in the foreground, and background,

Figure 1. The Electrical Ore-Finding Equipment at the Ealing Trials: The transmitting equipment is shown in the foreground. The receiving equipment is fixed on the tripod to the rear. It is probable that the two men standing on the right of the photograph are Leo Daft and Alfred Williams (extreme right) (Anonymous, 1902b).

respectively. The surveys were conducted by systematically varying the positions of both sets of electrodes. The receiving equipment is fixed onto a tripod and the observer notes changes to the signal, reported to be clicking sound, that he receives via a telephone type of earphone. In 1903, Daft and Williams patented their invention, entitled *'Improved Apparatus for Detecting and Localizing Underground Metallic Lodes'* (Intellectual Property Office, London, patent number 14,124, A.D. 1902). There is a very detailed description of the equipment, including circuit diagrams, in the patent documentation. Figure 2 shows the transmitting equipment.

4. "ORE-FINDER" DEMONSTRATIONS, FIELD TRIALS AN SURVEYS IN BRITAIN

The "Ore-Finder" equipment was used on a variety of metal mining sites in Britain. In addition, the company promoted several trials, where reporters were allowed to use the equipment, to give the technique wider publicity. However, all met with mixed success.

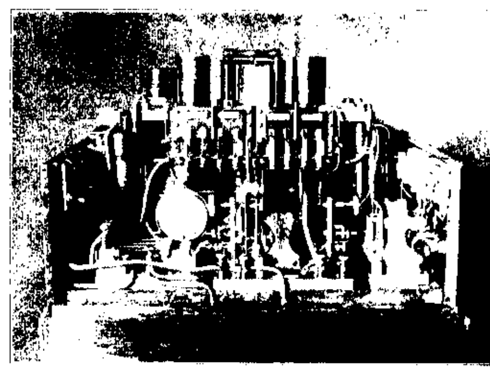


Figure 2. The Electrical Ore Finder transmitting equipment: A detailed circuit diagram is included with the patent held at the Intellectual Property Office, London, patent number 14,124, A.D. 1902 (Anonymous, 1903d).

Details of the first surveys by *The Electrical Ore-Finding Company* can be found in a Director's Report for 1902 (Anonymous, 1902). The surveys were conducted on the steep hillside of Copa Hill, above the Cwmystwyth Mine, Central Wales, to look for extensions to the mineral veins being worked at that time. The Directors Report contains a series of letters between Henry Gamman, the mine owner, and the Company. Gamman also became a Shareholder in *The Electrical Ore-Finding Company*, so it is possible that the shares may have been given as a payment, for allowing the surveys to be conducted at Cwmystwyth.

The Cwmystwyth survey results were widely quoted as being a success story. The veins had been identified as containing rich ore, and supposedly a new crosscut had proved the predicted vein and that 1000 tons of rich ore had been milled as a result of the survey. However, Gamman tried to dampen these exaggerated stories by writing a letter to the *Mining Journal*, putting the facts before the public. The 1000 tons of mined ore for example, was low grade and it was still lying unprocessed on the mountainside, and the crosscut towards an identified vein was still being driven (Gamman, 1903).

In February 1902, Daft and Williams set up a demonstration at Ealing Cricket Ground, London, for the press. About fourteen newspapers were represented. As there are no metal mines in London, a long piece of tin strip was buried in the ground to represent a mineral vein, as a substitute.

The tin strip was located by the surveys, but several reporters were not convinced about the validity of the trials, as a strip of buried tinplate could not possibly represent a mineral vein (Anonymous, 1903c). Williams argued that this was the best they could do under the circumstances, and would the Press go to an area away from London where there was a mineral vein, for a proper trial to be conducted? (Williams, 1903).

But the reporters were prepared to travel. On the 26th and 27th March 1903 a further trial was held at the Talacre lead mine, North Wales. This trial was slightly different as the electrode configuration was changed. Reminiscent of some of Robert Were Fox's early experiments, one of the transmitting electrodes was placed underground. From the equipment on the surface, a connecting cable was run 150 ft (46 m) down the main shaft, then along a 150 ft (46 m) long crosscut to the vein drivage, along which it was run a further 300 ft

(92 m) to the underground transmitting electrode located in a winze. The second transmitting electrode was located directly above on the surface. An extension of the vein was predicted but the outcome is not known. Certainly, Talacre mine produced very little lead ore the following years, so it is probable that this survey was not a success (Anonymous, 1903b).

Between 1901 and 1902 the *Company* had also carried out surveys in Cumbria in northwest England, and had proposed a survey at Llangynog lead mine in North Wales (Anonymous, 1902). However, much of their survey work does seem to have been concentrated in north-west England, with surveys being carried out at lead mines on Alston Moor, Westmoreland, and at several copper mines in the Coniston area, Cumbria, where one survey at Wetherlam Mine was reported to have found a poorly developed mineral vein (Franco, 1904). *The Electrical Ore-Finder Company* do at least seem to have had one moderate success with a survey for the *Barrow Haematite Steel Company Ltd.* This was conducted in September 1904 at the Park Mine, Dalton in Furness, Lancashire. It was reported in the *Times* newspaper (Anonymous, 1904c):- '*The instruments having located certain spots that contained haematite in ground that had not been previously worked, bores were put down.....and haematite ore has been struck at a depth of 83 ft* (25 m) *from the surface. This is within a few feet of the depth previously indicated by operators of the Ore Finding Company.*'

5. ELECTRICAL ORE-FINDER: WORLDWIDE SURVEYS

The 1902 Directors Report also gives some indication that future surveys may also be conducted worldwide as it was the intention of the Company to send an expedition to Spain to look for copper lodes. However, whether they did or not is not known, but certainly there is ample evidence of their later worldwide exploits.

Williams and Straker were still directors of the *Company* in 1904, but new blood had come on to the board, that included Andrew Anderson and Edward Dyer. Certainly *The Electrical Ore Finding Company* needed to manage the numerous patents they had taken out world wide, so to do this they formed *Andyer Ltd.* (derived from a combination of surnames) with the purpose to set up seven subsidiary companies worldwide to manage their interests and organise surveys (National Archives, Kew, London, BT31/10621/80368).

To date, none of these companies have been identified to suggest this worldwide expansion was realised, but it is known that patents were applied for in various Australian States (Victoria, New South Wales, Queensland, South Australia and Tasmania) and New Zealand in 1903. Similarly, patents were taken out in Africa (Transvaal, Natal, Orange River Colony, Cape Colony and Rhodesia) in the same year. Elsewhere applications were filed in the United States of America, Canada and Sweden (National Archives, Kew, London, BT31/10621/80368).

It has been possible to verify that patents were granted in Canada; the United States; Victoria, Australia; and Denmark, so perhaps some fundamental steps were in place for conducting surveys worldwide, or at the least allowing the equipment to be leased to a third-party in those countries.

5.1 Ernest Lidgey and the Hampton Plains Estate Limited

The use of the "Electrical Ore-Finder" system in Australia is well documented, and the equipment was used in at least four states thanks to the endeavours of Ernest Lidgey, an Australian mining geologist. Lidgey came to England in 1902 to promote Australian mining. He had previously been involved with gold mining in Victoria, and had later worked for the *Hampton Plains Estate*, Kalgoorlie, Western Australia. Whilst in England he had heard about the Daft-Williams system and witnessed demonstrations of the equipment.

In June 1903 Lidgey invited '*a number of gentlemen with mining interests, mainly from Western Australia*' to a meeting in London and explained in some detail how the Daft-Williams system could be used for finding gold (Anonymous, 1903d). Such was the interest generated that Lidgey acquired a license to use the equipment in Australia, and returned there with two electricians, where he was engaged by the *Hampton Plains Estate* to spend one week a month on mineral prospection. He arrived in Kalgoorlie in August 1903, and is credited with conducting the first geophysical surveys in Australia (Macgill, 2004). Initially surveys were conducted at the *Hampton Plains Estate,* a large collection of mining concessions lying to the south of Kalgoorlie, but such was the excitement generated by the technique, there was speculation that it would be used elsewhere on the goldfield (Anonymous, 1903f). At the end of August the equipment was in use on the Adeline lease of the *Hannan's Proprietary Company* (Anonymous, 1903g). Other mines were surveyed in the following months that included the *Associated Northern* (Anonymous, 1904a). However, it is not known how successful the surveys were in identifying new gold reserves.

5.2 Victoria, New South Wales and South Australia

In 1904, the equipment was taken to Ballarat gold mining area, Victoria, where it was operated by a Mr. Dawson, who was in charge of the electrical branch of the Ballarat School of Mines, and Mr. Allan Bowler, former Mayor of Scarsdale, a mining engineer, where the surveys were being conducted (Anonymous, 1904b). It is clear from newspaper articles that the intention was also to use the equipment in Queensland, and possibly the Northern Territory, and may have been used there during 1905, although no articles relating to that year have been discovered.

However, by October 1906 the rights to use the equipment had apparently been acquired by the *Cobar Corporation* of New South Wales. Surveys were testing the width and continuity of the Budgery Lode by the *North Cobar Exploration Company,* and at other mines there that included Mount Boppy (Anonymous, 1906 and 1907a).

In 1907, the South Australian Government was conducting a reassessment of mineral resources generally throughout the State, so the *Cobar Corporation* contracted to use the "Ore-Finder" equipment on a number of mine prospects. Some of the first surveys in South Australia were at Kapunda mine, where an inquisitive horse nearly got electrocuted to death by the equipment. This was followed by surveys at Kandina and Port Lincoln (Anonymous, 1907b).

The last known "Ore-Finder" surveys in Australia were conducted in October 1907 at Hamley Copper Mine, Moonta, South Australia. Based on the survey results, development work was commenced from a Treuer's Crosscut to intersect an 'identified' lode (Anonymous, 1907c). Newspaper reports indicate that the drivages were continued until the end of the year, but the survey was apparently a failure, as no identified veins were proved underground.

Despite the extensive number of surveys conducted in Australia, there are no photographs of the equipment being used, and no illustrations of the survey results have been found. It was only earlier in 2010 that the author found the documented results of two surveys conducted in Canada.

5.3 Nipissing, Ontario, Canada

Alfred Williams conducted two "Ore-Finder" surveys at the O'Brien Silver Mine, at Nipissing, Ontario, Canada. Canadian immigration records suggest that he visited Canada in 1904, but the surveys are reported in the book '*Silverland and its Stories*', (Gard, 1909), which gives a history of mining in the Nipissing - Cobalt areas.

The first survey (see Fig. 3) involved placing one transmitting electrode in the 60 ft (18 m) level of the O'Brien mine, and the other on the surface. The mining company had lost the mineral vein underground. The survey work indicated that the vein had in fact turned through nearly 90 degrees. In this example the vein had acted as a conductor.

In the second example (see Fig. 4), also conducted at the O'Brien Mine, a new vein was discovered. It is reported *'that surface earth was removed along the line of the identified vein and silver leaf was found at a depth of not over three feet'*. Apparently the survey was successful.

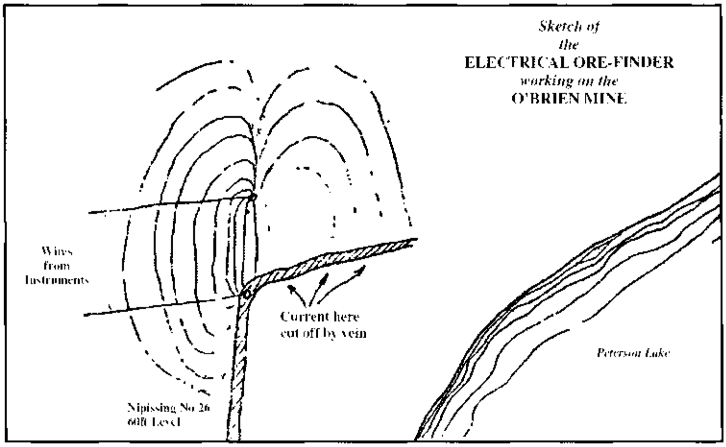


Figure 3. Sketch of the O'Brien Mine Survey, Nipissing, Canada: The transmitting electrodes places on the surface and underground in the 60ft (18m) level indicated that the mineral vein turned through nearly 90 degrees (Gard, 1909).

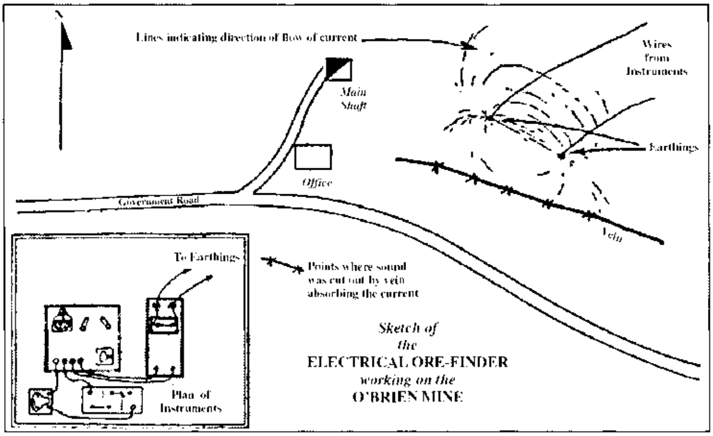


Figure 4. Sketch of the O'Brien Mine Survey, Nipissing, Canada: This survey identified a previously unknown mineral vein. The insert to the sketch shows the layout of the transmitting equipment (Gard, 1909).

6. THE FINAL YEARS

Despite the number of surveys conducted by *The Electrical Ore-Finder Company* over a period of five years in Britain, the *Company* never managed to make a break-through. Clearly the system had both its successes and failures. The last known survey in Britain was conducted in Cornwall in 1905 at Dolcoath Mine (Anonymous, 1905a).

Dolcoath Mine was a very successful copper - tin mine. It was located in the heartland of the Cornish mining industry, in probably one of the most intensely mined areas in Britain. The surveys were conducted to determine if any further veins existed north of the existing workings in the 'Great Flat Lode'. The Dolcoath management was pragmatic about the survey. They had to try the technique '*and were hopeful some good could come from the survey. That they could locate the vein he* [Director] *had no doubt, but whether they could determine, within a sufficient margin, that they would pay for working remained to be proved. That at present is the weak point of Electrical Ore Finding.*' In other words, the technique might detect an anomaly but no one could say with certainty what that anomaly represented.

By the end of 1905 it was all over for *The Electrical Ore-Finding Company Ltd.* and it went into receivership in December (National Archives, Kew, London, BT31/9016/66700). Three years later, *Andyer Ltd.* met a similar fate (National Archives, Kew, London, BT31/10621/80368).

However, it was not quite finished in Europe. Edward Kenyon Stow, one of the original directors of the Company was still carrying out surveys in Spain. Liquidator accounts indicate that Stow was hiring a set of "Ore-Finder" equipment. In 1905, he had persuaded Reginald Bonham-Carter a British Engineer at Linares, to supervise the sinking of a shaft to prove a vein he identified by surveying near to Reginald's mine, La Abundancia. The vein was expected at a depth of 100 ft (30 m) but after 150 ft (46 m) depth it had still not been encountered. Reginald was tragically killed in a mining accident in May 1906, but we know from the completion of Reginald's affairs that he was intending to sink the shaft deeper, but the exploratory work stopped, and the identified vein was never proved (Hampshire Record Office, Winchester, Bonham-Carter Collection 94M72 F402, F403 and F406).

Reginald Bonham-Carter also mentions in his correspondence that there were other "Electrical Ore-Finder" surveys in Spain, and this is confirmed by one article in the *Revista Minera* (Anonymous, 1905b) reporting that surveys were being conducted in the Sierra de Gador, Almería. The results of these surveys are not known, but together with those at Linares they were probably the last "Electrical Ore-Finder" surveys conducted in Europe.

7. WHY DIDN'T THE TECHNIQUE BECOME POPULAR?

There is no doubt that both Williams and Daft were both sincere and honest in the way they conducted their "Ore-Finder" operations. As pioneers in this field they would always have had difficulty in getting such an innovative technique accepted in mining circles, where reliability and profit were probably the main objectives. There are probably three main reasons why the "Electrical Ore-Finder" system never became a recognized exploration tool.

Firstly, the data was collected in a subjective manner. If the data had been quantified and recorded accurately, then Daft and Williams could have been in a position to analyse the data more precisely and perhaps make better judgements on its reliability. Franco (1904) recognised the weak point in data collection and remarked:- '*It is quite impossible for an untrained person to detect the almost inaudible sounds….so that an operator, to be really successful requires to have, not only a thorough knowledge of the system, but a very sensitive trained ear…*'.

Secondly, Williams and Daft were pioneers in their field and would not have the benefits of a database of previous experience to assist them in interpreting the surveys. Invariably, this would result in interpretation errors.

Thirdly, with the majority of surveys failing to identify mineral veins with accuracy, it would not be too difficult for the optimism expressed by mining companies to turn to pessimism, thereby giving the technique a bad reputation.

In 1912, Conrad Schlumberger was starting to conduct earth resistance surveys in the iron mining areas of France. The surveys were quantified and recorded accurately, and often considered to be the point in time when true geophysical prospection started, but perhaps this accolade could equally apply to Williams and Daft.

ACKNOWLEDGEMENTS

I would like to thank the Librarians at the Geological Society of London; National Coal Mining Museum, Wakefield; British Library, Colindale, London and the North of England Institute of Mining and Mechanical Engineers Library, Newcastle upon Tyne, England for information. I would also like to thank Margaret Vernon for comments.

REFERENCES

Anonymous 1902. *The Electrical Ore-Finding Company Ltd. Report of the Directors for 1902.* North of England Institute of Mining and Mechanical Engineers Library, Newcastle upon Tyne, England, 8 pp.

Anonymous 1902a. *The Daft and Williams system of electrical prospecting for mineral ores.* The Electrical Engineer, London, 260 pp.

Anonymous 1903b. *The Electrical Ore-Finding System.* The Mining Journal, Railway and Commercial Gazette, London. 73, 396 pp.

Anonymous 1903c. *Prospecting by Ear.* The Mining Journal, Railway and Commercial Gazette, London. 73, 168 pp.

Anonymous 1903d. *An Electrical Ore-Finding System.* The Mining Journal, Railway and Commercial Gazette, London 73, 743-748.

Anonymous 1903e. *Ore-Finding by Electricity.* The Illustrated London News, 192 pp.

Anonymous 1903f. *Kalgoorlie Mining.* The Advertiser, Adelaide, 7 pp.

Anonymous 1903g. *Kalgoorlie Mining.* The Advertiser, Adelaide, 8 pp.

Anonymous 1904a. *Western Australian Mining.* The Advertiser, Adelaide, 7 pp.

Anonymous 1904b. *A Fairy Tale of Science, the Electrical Ore Finder Vindicated.* Hawera and Normanby Star, New Zealand, 4 pp.

Anonymous 1904c. *Electrical Ore Finding.* The Times, London, 4 pp.

Anonymous 1905a. Dolcoath Mine, Limited. *The Mining Journal, Railway and Commercial Gazette* 76, 263.

Anonymous 1905b. Investigaciones electro-mineras en Sierra de Gador. *Revista Minera* 56, 270.

Anonymous 1906. *The Budgery Mines.* The Sydney Morning Herald, New South Wales, 10 pp.

Anonymous 1907a. The Electrical Ore-Finder – Being Largely Used. The Sydney Morning Herald, New South Wales. 2nd January, p.13.

Anonymous 1907b. *Searching for a Copper Lode.* The Advertiser, Adelaide, 4-6 pp.

Anonymous 1907c. *Hamley Copper Mine.* The Advertiser, Adelaide, 9 pp.

Franco, S.F. 1904. Electrical Ore-Finding. *The Mining Journal, Railway and Commercial Gazette, London*, 76, 85.

Gamman, H. 1903. Electrical Ore-Finding at the Cwmystwyth Mine. *The Mining Journal, Railway and Commercial Gazette, London*, 74, 44.

Gard, A.A. 1909. *Silverland and its Stories*. Emerson Press, Toronto, Canada, 89-91

Macgill, G. 2004. The King's Battery and Mr Lidgey's Grand Vision for the Hampton Plains. *Journal of Australasian Mining History*, 2, 194.

Sweet, G.E. 1978. *The History of Geophysical Prospecting: Volume II (3rd edition)*. Neville Spearman, Suffolk, 385 pp.

Vernon, R.W. 2007. 'A Very British Enterprise' the History of Geophysical Prospection for Minerals in Britain in the 19th and early 20th Century. *7th International Mining History Congress*. Society of Geoscientists and Allied Technologists. Bhubaneswar, India, 1-13.

Vernon, R.W. 2008. Alfred Williams, Leo Daft and 'The Electrical Ore-Finding Company Limited'. Memoirs 2008. Northern Mine Research Society, Sheffield, South Yorkshire, UK. *British Mining*, 86, 4-30.

Vernon, R.W. 2009. The Early History of Geophysical Prospecting in England and Wales. The Lode of History. *Proceedings of the Welsh Mines Society Conference 2007*. The Welsh Mines Society, Llanaber, Gwynedd, Wales, Welsh Mines and Mining, 1, 77-81.

Williams, A. 1903. *The Electrical Ore-Finding System*. Westminster Gazette. 6th February. The Electrical Ore-Finding System: Press Notices. North of England Institute of Mining and Mechanical Engineers Library, Newcastle upon Tyne, England, 28-29.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

FROM FAILURE TO ACHIEVEMENT: THE RELATIONSHIP BETWEEN THE PORTUGUESE GEOLOGICAL SURVEY AND THE MINING SECTOR, IN THE 20TH CENTURY

Teresa Salomé Mota

Inter-university Centre of History of Science and Technology; Museum of Science of the University of Lisbon,
Rua da Escola Politécnica 56, 1250-102 Lisboa, Portugal.
salome.teresa@gmail.com

Abstract. In the early 20th century, the Portuguese mining sector faced a difficult situation, which the State tried to overcome through regulations. The context seemed encouraging to the development of geological studies and it was expected that the State would support the Portuguese Geological Survey (PGS). Nonetheless, that did not happen. The limited resources ascribed to the PGS in the years bridging the two world wars show that the Portuguese State was quite unaware of the role of a Geological Survey, and it was only in the 1940's that the situation began to change. After the Second World War, the pace of the country's economic growth brought about optimal conditions for the development of the mining sector, a source for many of the raw materials used in industry. Geological maps were crucial for the survey of mineral resources and as a consequence the PGS could now count on enlarged resources intended for their production and publication. The continuing difficult situation faced by the institution changed because geological mapping became considered as a key instrument in the development of the mining sector. Therefore, the change took place regardless of the significance of the PGS as a scientific institution; for the Portuguese State it was only the 'useful' aspects of geology that really mattered.

1. INTRODUCTION

In the early 20th century, the mining sector was a source of concern for the Portuguese State. One of the main features of the underdevelopment of Portuguese economy was a large primary sector and negligible industrialisation. Mining, in particular, was rudimentary despite a period of greater activity, during the Regeneration *(Regeneração)* (c. 1851-1868) (note: The *Regeneração* was a period during the 19th century that enabled the rise of embryonic capitalism in Portugal, based on a set of policies focused on the development of public works).

The most important mining concessions were in foreign hands; those owned by Portuguese companies were but a few exceptions (note: It is the case, for example, of the São Domingos mining (pyrite, copper and zinc) and the São Pedro da Cova coal mining). The majority of mining concessions was small and scattered all over the country and their activity was irregular or even non-existent. In the few mines actually working, their owners did not resort to geological data or specialised personnel. National entrepreneurs did not invest in the mining sector because large sums were needed and financial risk was too high. This state of affairs did not grant any efficient and proper exploitation of mineral resources, and therefore the significance of the mining sector and related activities in Portugal's economy was negligible (Medeiros, 1978; Cabral, 1979; Direcção Geral de Geologia e Minas, 1990; Guimarães, 1995).

The succeeding regimes in Portugal between the two world wars – the First Republic, followed by a military dictatorship, and finally the *Estado Novo* (note: The Estado Novo was a dictatorship led by António de Oliveira Salazar, formally established in 1930 and over by 1974) – took some legislative measures in order to reverse – or at least, improve – the situation, but these measures were not always successful. Some of them assigned a role to the Portuguese Geological Survey (PGS) (*Serviços Geológicos de Portugal*) in the resolution of some of the problems faced by the mining sector.

2. THE PORTUGUESE MINING SECTOR IN THE YEARS BETWEEN THE TWO WORLD WARS

2.1 Mining legislation

The First Republic (note: The First Republic was established in Portugal in 1910, after the fall of Monarchy. It ended abruptly in 1926 with a military *coup d'état*) tried to solve the problem of Portuguese mining chiefly by introducing a considerable amount of legislation (Note: not all legislation introduced will be considered in this article. Only the legal measures which issued guiding lines for the mining sector together with those in which the role of the Portuguese Geological Survey is considered relevant will be taken into account.). Particularly significant is Act 4 641, issued in 1918, which created the General Directorate of Mines and Geological Survey (GDMGS) (*Direcção Geral de Minas e Serviços Geológicos*), of which the PGS was a part. This Act emphasised the need of the PGS for a better organisation, an indispensable precondition to the development of the mining sector: 'geological surveys and mines have an intimate relationship, as it is recognised in countries where geological science and mining are more advanced' (Act 4 641, 14 of July 1918). As a result, the PGS would be in charge of the 'preparation of geological maps' and the survey of mineral resources (Act 4 641, 14 of July 1918).

In 1926, a *coup d'état* replaced the First Republic for a military dictatorship but the way the latter dealt with the issues in the mining sector did not differ much from their predecessors. New legislation was introduced, that related to fossil fuels being particularly relevant: Portugal depended heavily on foreign energetic resources and this was one of the most troubling aspects of the country's economy (Vianna, 1928; Guimarães, 1995).

A Commission for the Use of Domestic Coal (CUDC) (*Comissão de Aproveitamento dos Carvões Nacionais*) was created with the aim of studying domestic fossil fuels, coal in particular. The CUDC operated in close relation with the GDMGS, especially with the PGS, which carried out geological studies and geological mapping of fossil fuels outcrops. The legislation also established a minimum mandatory annual production of fossil fuels. If concession owners had no financial capability to comply with such resolution, they could expect some help from the State such as government-subsidized loans (Act 11 852, 6 July 1926).

When the *Estado Novo* was established in 1930, it dealt with the problematic situation of the mining sector in a less traditional way: fewer laws were issued, but they were more efficient.

In August 1930, Act 18 713, which regulated mining was published. It established the State as the sole owner of all mineral deposits in the Portuguese territory, but they could be exploited by private mining companies (Decree 18 713, 1 August 1930). In other words, private entrepreneurship was now put in charge of the development of the mining sector, but under the control of the Portuguese State.

In 1933, the CNAC was replaced by a new institution, the Portuguese Institute for Fuels (PIF) (*Instituto Português de Combustíveis*), whose mission was investigating the availability of all kinds of fossil fuels, and the gathering of a multitude of scattered institutions associated with their research and use (Act 22 788, 29

July 1933). It was expected that PIF might take the right measures in order to attract private entrepreneurship, improve mining management, and develop connections between mining and other economic sectors such as electricity and metallurgy (Act 22 788, 29 of July 1933). As its predecessor, PIF continued to work in tight association with the PGS, especially in geological surveying and prospecting of coal deposits (Ministry of Trade and Industry, 1936).

All these circumstances seemed favourable to the success of geological research, which was now oriented to the mining sector. In this context, it was expected that the Portuguese State would support its Geological Survey, as it was common in other countries (Wilson, 1985; Rabbitt, 1989; Vodden, 1992), but despite all good intentions expressed in the legislation issued between the two world wars, the PGS had never faced such difficult times.

2.2 The situation of the PGS and its relationship with the mining sector

Act 4 641 placed the PGS in a situation of almost complete dependence on the GDMGS. Most of its technical staff had to be civil servants belonging to the corps of engineers and mining technicians, but many of them were not fully prepared to carry out the majority of geological tasks, fieldwork and geological mapping, in particular. As the PGS' staff was much limited, it was unable to accomplish all required tasks (Mota, 2007a,b; Carneiro and Mota, 2007).

The PGS was also financially dependent on the GDMGS, and was ascribed a meagre annual budget. It struggled with severe financial difficulties and even current expenses such as the acquisition of scientific books or topographic maps, had to be authorized by the GDMGS (Mota, 2007a,b; Carneiro and Mota, 2007).

The PGS staff spent most of its time doing administrative and bureaucratic tasks as it had to respond to countless requests from various public and private institutions; consequently, there was not much time left to carry out their primary task, geological surveying and scientific research. The institution's autonomy was so restricted that it did not allow for the establishment of a plan with clearly defined aims and working priorities, by articulating the normal tasks of a civil service with the production of scientific work (Mota, 2007a,b; Carneiro and Mota, 2007).

The difficult situation of the PGS was greatly due to the State's inability to fully understand the role that this institution could play in surveying and prospecting mineral resources. The measures concerning the geological study of the Portuguese territory present in mining legislation seem to be no more than good intentions or even mere rhetoric. The laws passed determined that geological mapping had to be carried out, but no specific information about the scales of the maps and deadlines were given, and nobody seemed to know how the expenses involved would be paid. There was not a clear, detailed, and precise policy concerning the geological survey of the country and its mineral resources. The relationship between the PGS and the mining sector can be summed up to a few timely tasks requested by the GDMGS. The PGS had no conditions to perform any particular role in the resolution of the difficult situation the mining sector was facing.

In the years bridging the two world wars, geology and the PGS seemed to be almost irrelevant to the Portuguese State but those were also the years when Portugal was striving with serious political, social and financial problems, and with three different political regimes coming one after another. In a time of crisis, the importance of geology and of the PGS was certainly a minor problem among those faced by the successive political leaders.

3. THE PORTUGUESE MINING SECTOR IN THE DECADES AFTER THE SECOND WORLD WAR

3.1 A harbinger of change

Up to the 1930's, the Portuguese mining sector did not show any significant improvements (Nogueira, 1941). During this decade an industrialist movement led mainly by engineers began making its voice heard by the *Estado Novo*. They were well aware of national backwardness and considered the weak industrialisation one of the main reasons underlying the nation's economic and social underdevelopment. Science and technology were considered fundamental to reverse the situation, and consequently should be promoted by the State. Among other measures, the industrialists advocated the development of some mineral industries (copper, tin, and wolfram), the nationalisation of mineral resources, the establishment of iron smelting, and the reduction on the price of energy (Rosas, 1986; Brito, 1988; Diogo, 1994).

Most of these measures were not major priorities for Salazar, the dictator who ruled Portugal with a firm hand. Despite the limitations imposed by Salazar's political and economic policies, by the end of the 1930s the regime became interested in the development of industry and the knowledge of Portuguese mineral wealth was considered highly relevant. New legislation intended to improve the mining sector was introduced in 1939; Act 29 725 created the Service for Mining Improvement (SMI) (*Serviço de Fomento Mineiro*) in the context of the GDMGS. The SMI aimed to survey and prospect mineral resources existing in the Portuguese mainland (Act 29 725, 28 of June 1939), and was the culmination of all the measures advocated by the industrialist movement for the mining sector (Mota, 2009).

The GDMGS then outlined a plan for the country's mining survey. The plan stipulated that it was of primary importance to identify gold and iron deposits: the first because its price was less susceptible to market ups and downs, and the second because of its importance in the context of the iron smelting industry that would be established in Portugal. In order to enable the SMI to carry out its tasks, the PGS would have to proceed with the geological survey of the Portuguese mainland and the publication of geological maps was considered a priority (Castro e Solla, 1942/1943).

After the establishment of the SMI and all through the 1940's and the 1950's, several representatives of the Portuguese National Assembly began questioning the lack of attention given to the PGS (Note: during the Estado Novo, representatives of the political power were distributed between the Chamber of Corporations and the National Assembly. The latter had legislative purposes and intended to supervise the government and public administration. However, the National Assembly lost its significance at the same time as Salazar's regime became more and more imposing). They criticized the scarce funds allocated to the institution and its subsequent incapacity to accomplish the tasks required, in particular geological mapping, and urged the need to intensify the pace of production and publication of geological maps, which began to be considered chief instruments in the development of the mining sector and, therefore, the country's economy (Diário das Sessões da Assembleia Nacional, 1940–1962).

This shows that something was beginning to change in the way the political power perceived the PGS, geology and, particularly, geological mapping. Their role in the knowledge of the country's mineral wealth, and consequently in its industrial and economic growth, was now being taken into account. It is not a mere coincidence that this change happened as the Portuguese geological community was coming to life and asserting itself (Mota, 2009). This was, however, only a harbinger of change; it was still too incipient to have any significant consequences. In the GDMGS, geological surveying and mapping remained the outcome of a conjunction of circumstances rather than a result of any strategic planning regarding the role of geology in surveying and prospecting mineral resources.

However, the difficult situation the PGS was living for a long time did not change. Although the geological survey of Portuguese mainland and the publication of geological maps had been reinforced, the same happened with the problems and needs of the institution: lack of space in deteriorated facilities, low budgeting, and increasing bureaucracy. The PGS remained underfunded and understaffed and, subsequently, unable to fulfil its renewed functions. Just the opposite of what happened with the SMI, which was endowed with substantial financial and human resources. Most certainly, geology and the PGS were still not considered essential in the context of mining activity (Mota, 2007b; Carneiro and Mota, 2007).

3.2 The golden years

During the Second World War, the process of industrialisation occurring in Portugal slowed down but, as soon as the conflict ended, the industrialists sounded voices once again. A new and strong wave of industrialisation took place, mostly by State initiative, and guided by political and economic measures envisioned in three successive Improvement Plans (*Planos de Fomento*), and carried out between the 1950's and the 1970's (Lima, 1987; Brito, 1989; Rosas, 1990).

During these decades, Portugal underwent deep social and economic change. In the 1970's, the pace of economic growth was the greatest ever and this context was favourable to the development of the mining sector. Mineral resources found and exploited were quite substantial and used in several industrial activities —concrete, glass, pottery— which significantly contributed to the Gross Domestic Product. The exploitation of building stones, clay, and sand, until then not so common, also broadened new economic opportunities in national and international markets.

The development of the mining sector occurred in the same legal context as before. The mining Act of 1930 and the one that created the SMI, in 1939, were still the main documents orienting this industry (Carneiro, 1959; Carneiro, 1971). But, what actually set the difference were the measures anticipated in the Improvement Plans. Surely, they pressed the need to proceed with the survey of the Portuguese territory and hastened the publication of geological maps but now an appropriate plan was defined and suitable financial means were located and the measures properly implemented (Planos de Fomento, 1953-1973).

The implementation of these Improvement Plans proved critical to the PGS as an institution; they caused a significant change in the adverse conditions the institution faced. The PGS was then endowed with significant amounts of money, especially for making of the Geological Map of Portugal (*Carta Geológica de Portugal*) in the scale 1:50, 000, which is then considered a 'key element to the survey and research of mineral resources' (Planos de Fomento, 1953-1973). The PGS was able to contract more technical personnel, especially geologists and field assistants. In 1919, there was not a single geologist among the PGS technical staff; in 1940, there was one; in 1974, there were 13 geologists and 10 field assistants. More money and a larger staff meant more fieldwork and a faster pace in the production of geological mapping, in particular maps in the scale 1:50, 000, the most significant taking into consideration the purposes of the Portuguese State. Making and publishing geological maps were then the institution's main aims (Mota, 2007). These new circumstances enabled the PGS to proceed with a consistent plan of geological research. For the first time in a long time, the PGS reasserted itself as a true scientific institution (Mota, 2007).

4. CONCLUSIONS

Contrary to what has been upheld by some authors, the close relationship between the PGS and the Portuguese State's mining interests was not the major factor in the institution's poor scientific achievements during the first decades of the 20th century (Teixeira, 1941/1942; Almeida and Carvalhosa, 1974; Neiva, 1998). Even if the overwhelming dependence of the PGS on the GDMGS was the main reason behind many of its problems, it was the importance given to mining issues by the Portuguese State that, in the end, offered the PGS the opportunity, and the means, to overcome its difficult situation and become more than a simple public service.

Geological mapping played a decisive role in this process, as it came to be perceived by the Portuguese State as a crucial instrument in the expansion of some industrial and economic sectors. The GDMGS also acknowledged the importance that geological mapping played in its main task: the survey and exploitation of mineral resources. Geological maps became a kind of 'interface' in which the interests of the Portuguese State, the GDMGS, and the PGS coexisted and were reconciled.

However, it is important to emphasise that the overturn in the PGS situation is not a consequence of the acknowledgment of its intrinsic significance as a scientific institution. It was either a 'collateral effect' of the *Estado Novo*'s commitment to industrialisation and of the primacy given to geological mapping in the development of the mining sector. The Improvement Plans clearly stated that the budget ascribed to the PGS should be spent in 'geological applied research', in particular in geological mapping, in order to improve the mining sector. Only the 'applied' or 'useful' features of geology were really important in the acknowledgment of the PGS and this also explains its persistent secondary position in the context of the GDMGS. Even so, the PGS was able to take advantage from the positive circumstances existing in Portugal after the Second World War and hence defend its own interests as a scientific institution.

ACKNOWLEDGEMENTS

The author is grateful to Teresa Lopes for her help in the translation of this paper. The research underlying this paper was carried out in the context of the project 'Das Comissões Geológicas aos Serviços Geológicos (1848-1970): História e Herança Científica', PTDC/HCT/65345/2006, funded by Fundação para a Ciência e a Tecnologia, Portugal, (2007-2011).

REFERENCES

Almeida, F.M. and Carvalhosa, A.B. 1974. Breve história dos Serviços Geológicos em Portugal. *Comunicações dos Serviços Geológicos de Portugal*, 63, 239-265.

Brito, J. M. B. 1988. Os Engenheiros e o pensamento económico do Estado Novo. In: Cardoso, J.L. 1988. *Contribuições para a história do pensamento económico em Portugal*. Dom Quixote, Lisboa, 209-234.

Brito, J.M.B. 1989. *A industrialização portuguesa no pós-guerra (1948—1965). O condicionamento industrial*. Dom Quixote, Lisboa, 65-70.

Cabral, M. V. 1979. *Portugal na alvorada do século XX*. A Regra do Jogo, Lisboa, 37-40.

Carneiro, A. and Mota, T.S. 2007. The Geological Survey of Portugal (1857-1948), an overview. *Earth Sciences History*, 28, 85-96.

Carneiro, F.S. 1959. A riqueza da indústria extractiva metropolitana. *Estudos, Notas e Trabalhos*, 13, 65-216.

Carneiro, F.S. 1971. *Potencialidades minerais da metrópole, base firme de desenvolvimento industrial do país*. Arquivos da

Direcção Geral de Minas e Serviços Geológicos, Lisboa, 25-27.

Castro e Solla, L. 1942/1943. Proposta de plano geral de reconhecimento mineiro do país. *Relatórios do Serviço de Fomento Mineiro,* 1, 3-45.

Decree 4 641, 14 July 1918, 1290-1305.

Decree 11 852, 6 July 1926, 698-705.

Decree 18 713, 1 August 1930, 1237-1250.

Decree 22 788, 29 July 1933, 723-740.

Decree 29 725, 28 Jun 1939, 452-479.

Diário das Sessões da Assembleia Nacional, 1942–1962.

Direcção Geral de Geologia e Minas, 1990. *Estudos Notas e Trabalhos do Serviço de Fomento Mineiro: Tomo comemorativo do 50º aniversário do Serviço de Fomento Mineiro, 1939-1989.* Direcção Geral de Geologia e Minas, Porto, 15-18.

Guimarães, P.E. 1995. A intervenção do Estado Novo na indústria mineira: a criação do Serviço de Fomento Mineiro. *Boletim de Minas,* 32, 203-212.

Planos de Fomento, 1953-1974.

Lima, M. P. 1987. Contribuição para uma história da organização racional do trabalho em Portugal no contexto da economia sob o Estado Novo (19261959). In: Pinto, A.C. (ed.), *O Estado Novo - das origens ao fim da autarcia (1926-1959), volume I.* Editorial Fragmentos, Lisboa, 325-336.

Diogo, M. P. 1994. *A Construção de uma identidade profissional, a Associação dos Engenheiros Civis Portugueses, 1869–1937.* Ph.D. dissertation (not published), New University of Lisbon, Lisbon, 140 pp.

Medeiros, F. 1978. A sociedade e a economia portuguesas nas origens do salazarismo. A Regra do Jogo, Lisboa, 34-50.

Ministério do Comércio e Indústria 1936. *Arquivos do Instituto Português de Combustíveis,* Lisboa, 5-15.

Mota, T. S. 2007a. A mere shadow of an institution: the unhappy story of the Portuguese Geological Survey (PGS) in the period between the two world wars. *Annals of Science,* 64, 19-40.

Mota, T. S. 2007b. *Os Serviços Geológicos entre 1918 e 1974: da quase morte a uma nova vida.* Ph.D. dissertation (not published). New University of Lisbon, Lisbon, 183 pp.

Mota, T.S. 2009. Os olhos da Geologia, o discurso dos engenheiros e o saber dos geólogos: o início da utilização de métodos geofísicos na prospecção de recursos minerais em Portugal. *Comunicações Geológicas,* 96, 129-142.

Neiva, J.M.C. 1998. Comissões e Serviços Geológicos e Carta Geológica de Portugal. *Boletim de Minas* 35, 391-399.

Nogueira, A.M. 1941. Elementos para o estudo da indústria mineira em Portugal nos anos de 1930 a 1939. *Boletim de Minas* 1, 3-93.

Planos de Fomento, 1953-1973.

Rabbitt, M.C. 1989. *The United States Geological Survey, 1879-1989.* United States Geological Survey, 5-7.

Rosas, F. 1986. *O Estado Novo nos anos trinta (1928-1938).* Imprensa Universitária/Editorial Estampa, Lisboa, 33-60.

Rosas, F. 1990. *Portugal entre a paz e a guerra, 1939-1945.* Imprensa Universitária/Editorial Estampa, Lisboa, 43-49.

Teixeira, C. 1941/1942. Introdução. *Boletim da Sociedade Geológica de Portugal,* 1, 3-5.

Vianna, A. 1928. Problema dos carvões nacionais. *Boletim de Minas,* 1, 6-18.

Vodden, C. 1992. 150 years in the history of the Geological Survey of Canada. *Episodes,* 15 (2), 101-108.

Wilson, H.E. 1985. *Down to Earth.* Scottish Academic Press, Edinburgh, 12-15.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources.* Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

MINERAL RESOURCES SURVEY ON THE CHINESE BORDERLANDS: THE SINO-SWEDISH SCIENTIFIC EXPEDITION (1920S AND '30S)

Jiuchen Zhang

Institute for the History of Natural Science, Chinese Academy of Sciences,
55 Zhong Guancun East Road, Beijing, 100190, China.
zjc@ihns.ac.cn

Abstract. The six-year survey of the Sino-Swedish Scientific Expedition from 1927 to 1933 occurred at the same time, and promoted, an upsurge period for the exploitation of the natural resources of western China. Chinese geologists paid much attention to mineral resources in the western regions and made significant advances. Analyzing the Chinese geologists' reports only, this paper summarizes their contributions and their social influence. Reasons are given why Chinese geologists paid so much attention to the mineral resources of the western border regions.

1. INTRODUCTION

On 9 May 1927, the Sino-Swedish Scientific Expedition to the northern and western Provinces of China under the leadership of the Swedish explorer and scholar Sven Hedin (1865-1952) and the Chinese scholar Bingchang Xu (1888-1976) began its six-year journey. It was the first large-scale international academic cooperation undertaken in China.

The team included scholars from a variety of disciplines (see Table 1) and the work covered large areas in northwestern China (see Fig. 1). The achievements included the collection of Palaeozoic specimens, the establishment of weather stations, topographic surveys, archaeological discoveries, etc. A mineral resources survey was one of the team's most important achievements, which has largely been neglected by modern historians.

2. WHY THE SURVEY PAID ATTENTION TO THE MINERAL RESOURCES OF THE WESTERN BORDER REGIONS

The 61-year-old Hedin arrived in Beijing at the end of 1926. It was the fifth time he had been to China. Engaged by Lufthansa to survey a new air route from Berlin to Shanghai, he intended to organize a large-scale survey in western China. Having previously undertaken explorations there for nearly ten years, Hedin was already familiar with the area. This time he led a team with Swedish, German and Danish members and intended to continue survey work as before.

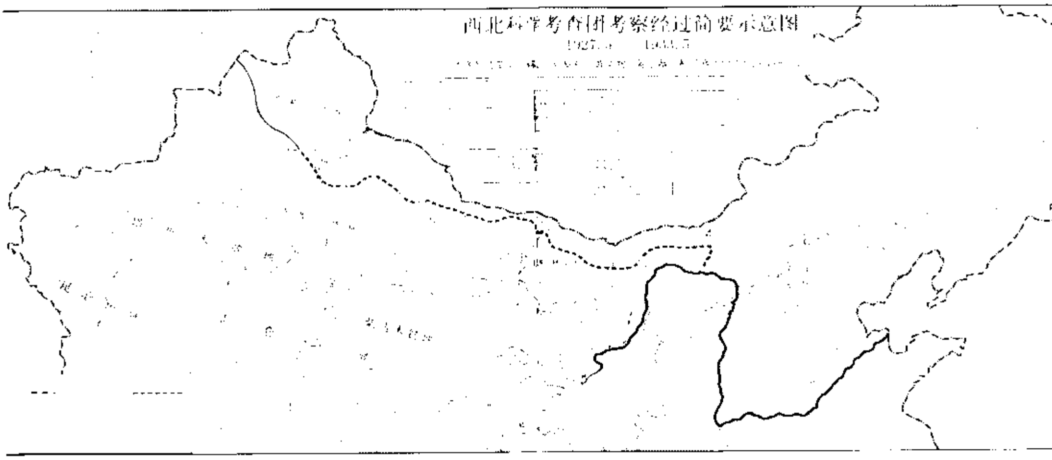


Figure 1. Sketch-map of the routes of the Sino-Swedish Scientific Expedition to the north-western provinces of China *(xi bei ke xue kao cha tuan kao cha jing guo jian yao shi yi tu)* (Thick dotted line = route of the team led by Sven Hedin and Xu Bingchang in 1927. Thin dotted line = route surveyed by the Chinese investigators. Thin unbroken line = route taken by the joint Chinese and Western survey. The boxes on the map, except right one, indicate important discoveries made during the survey. Among them, the top-right rectangle indicates the locality for the discovery of the *Bai Yun E Bo* iron ore. Small circles = major places visited during the expeditions. Large circle = Beijing).

Chinese: 14 members	**Westerners: 30 members**
Xu Bingchang (leader)	Sven Hedin (leader)
Yuan Fuli (geologist)	B. Bohlin (paleontologist)
Ding Daoheng (geologist)	E. Norin (geologist)
Huang Wenbi (archeologist)	F. Bergmen (archeologist)
Chen Zongqi (geophysicist)	N. Ambolt (astronomer)
Hao Jingsheng (botanist)	N. Horner (geologist)
	G. Bexell (geologist)
	G. Montell (ethnologist)
	T. J.Arne (archeologist)
	W. Haude (meteorologist)
Cartographer, students for weather observation, etc.	Cameramen, air-crew, etc.

Table 1. The chief members of the survey team.

2.1 Negotiations between Hedin and the 'Chinese Academic Association'

The Chinese social environment had changed greatly since Hedin's previous visit in the 1910s. After several political and cultural movements led by intellectuals who had been educated in modern science, Chinese scholars had become imbued with a new awareness of the significance of science and technology.

When Hedin arrived in Peking, he requested support from the Swedish and German embassies, the Peking Government, and even the Chinese military. It seemed that his plans initially went off without a hitch. At that time, the Swedish geologist J. G. Andersson was advisor to the Ministry of Agriculture and Commerce of the Peking Government. He suggested that Hedin should cooperate with the Chinese Geology Survey (CGS), which was under the aegis of the Ministry of Agriculture and Commerce. After various negotiations, Hedin signed a cooperation agreement with the CGS, according to which the Survey would provide two geologists to participate in Hedin's team. But there was a clause in the agreement that all geological, archeological and historical materials should be sent to Sweden. This caused national outrage! Some Chinese newspapers even reported that Hedin had come to China with aeroplanes and wanted to appropriate cultural relics from China.

So Hedin's plan was initially opposed by the Chinese academic community. On 5 March 1927, fourteen institutes from different academic fields established the Chinese Academic Association (CAA) at Peking University. One of its aims was to oppose foreigners entering China and collecting academic information or specimens without Chinese permission. After its establishment, the CAA began negotiations with Hedin, which lasted for nearly six weeks.

The Chinese scientific community paid attention to many aspects of the Survey. On the one hand, people were concerned about its aims, such as whether or not it involved military matters, the identity of the Western members, and whether or not they were military men, etc. They were also interested in the Survey's route, the time it might take, and the possibility of cooperation. After due negotiation, the CAA concluded a treaty of cooperation and collaboration, which is considered by Chinese scholars to be the first 'equal treaty' in Chinese history.

Mineral resources were not included in the Survey's brief at the period of negotiations between Hedin and the CAA. During the negotiations, Hedin simply pointed out that the geological survey work would include petrology and paleontology, which did not imply a mineral survey (Notes of negotiations between Seven Hedin and Chinese scholars, *The Report of the Scientific Survey in Northwestern China*, Chinese Academic Association, 1928). Personally, Hedin had no special interest in mineral resources. But he wanted to avoid doubts and suspicions as to the Survey's motives.

At the time, China was faced with a serious crisis due to foreign aggression so her mineral resources were related to the national economy and national defence, especially in the borderland areas. As they had no specific goals related to mineral resources, most of the Western geologists did little work on this subject during the Hedin Survey. Although they did mention mineral resources in their reports, such matters were only of academic interest to them; and their investigation was not one of their primary tasks during the work of the Survey. By contrast, the Chinese geologists paid much attention to mineral resources. And in fact the first major achievement of the Survey was the discovery of the *Bai Yun E Bo* iron ore deposits in Inner Mongolia (see Section 3.1), which exerted a tremendous influence in and on Chinese society.

2.2 Why China paid much attention to the mineral resources of the border regions

From the 1920s, there were various crises along the Chinese borderlands. So Chinese people called for the exploration of borderland areas and the strengthening of national defence. On 18 September 1931, Japanese forces invaded northeastern China, and this encouraged a wave of exploration in the northwestern areas of the country so that the Chinese Government, and society more generally, began to pay much greater attention to exploring and exploiting the natural resources of northwest China. During this period, many organizations and survey teams were established (see Table 2). And the Chinese Government also made plans for the long-term exploitation of resources in western China. The main focus of the investigations was on mineral resources, which included petroleum, coal and iron – the kinds of resources that are symbols of modern society and provide the foundation of modern industry and national defence.

Name of the Survey	Dates	Number of team members	Supporting organization	Achievements
Academic Survey in Western China	1931		Chinese Government	*Report (unpublished)*
Northwestern Survey Team	1932	8	Changjiang News Agency	*Report on Exploiting Northwest China*
Industrial Survey Team	1932	44	Longhai Railway Bureau	*Industrial Plan*
Northwestern Survey Team	1937	> 20	Fund Committee	Many academic papers in geology, geography, archaeology, etc.
Industrial Survey Team	1942		Chinese Economic Ministry	*Report (unpublished)*
Northwestern Survey Team	1942-1943		Academia Sinica	Survey of geography, history, and society
Northwestern Constructing Survey Team	1943	> 30	Chinese Government	*The Report of the Northwestern Constructing Survey Team*

Table 2. The main survey teams for the exploitation of Northwest China (1930s-1940s).

There are abundant mineral resources in northwest China. But as it is a remote region with considerable transport problems, and the distribution and reserves of the mineral resources in this area were little known before the 1930s. The natural environment is nothing short of atrocious in northwest China! With a vast area, the geography is complex and harsh. It has a continental climate, with aridity and desiccation. It is therefore not at all favourable for the development of agriculture. During the 1920s and '30s successive droughts hit the area, and severely affected its agriculture. Therefore, attention was turned to prospecting for mineral resources, which could provide the best way to bring about economic development in the area.

In the 1930s, eastern China had 98% of the country's population, but less than 50% of the land. On the other hand, northwestern China (including many provinces, such as the western part of Inner Mongolia, Gansu, Ningxia, Shaanxi, Qinghai, Xinjiang, etc.) had a vast area with abundant mineral resources. But it was under-populated. Therefore, these areas were considered suitable for immigration and settlement.

Western China also had, and has, an important strategic position in China. It is the communication center of Eurasia and has a long frontier with many other Asian countries. But largely due to transport difficulties and obstacles, the mineral resources had not been explored adequately.

3. THE SURVEY'S MAIN DISCOVERIES RELATING TO MINERAL RESOURCES AND THEIR SOCIAL INFLUENCE

The Hedin Survey left Beijing on 9 May 1927 and arrived in Inner Mongolia's large city, Baotou, by train, the following day. The team stayed there for two months, buying and preparing survey materials, etc, such as camels, which were the main means of the transportation. On 1 July, the Survey started its journeys with three teams: southern, northern and central.

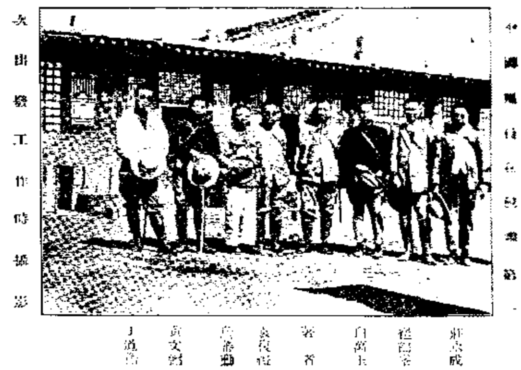


Figure 2. Chinese members of the team. (The first person from the left is Ding Daoheng. Yuan Fuli is fourth from the left.).

3.1 The discovery of the Bai Yun e Bo iron ore deposits in inner Mongolia

There were two Chinese geologists in the team: Ding Daoheng and Yuan Fuli (see Fig. 2). Only the third day after the northern team set out, Ding discovered the main deposit of the iron ore at *Bai Yun E Bo*, while his colleagues were discussing fieldwork plans in a tent. In early August, Yuan found the western deposits of the iron. (In Mongolian, *Bai Yun E Bo* means 'rich sacred mountain'.) According to Ding's estimate, the reserves were of the order of thirty million tons, of high quality ore and easy to exploit. The deposits would come to be the basis of the second largest iron mine in China.

Ding thought it was a high-grade ore, and wrote about the discovery to the Chinese team leader, Xu Bingchang. Xu was impressed by the description of the discovery. As there was no precise topographic maps for the area of iron ore (or indeed for the whole survey area), Xu transferred a cartographer from the southern team to the northern one to help Ding compile a map of the potential mining area.

The *Bai Yun E Bo* discovery exerted a tremendous influence on Chinese society. In January 1929, Chinese newspapers reported the discovery and predicted that it would be one of the largest bonanzas in China. The discovery also made the Survey much better recognized in China and in 1932 the Chinese Government published four souvenir stamps for the Survey – the only souvenir stamps about science in the first half of the twentieth century (see Fig. 3). In 1933, a Chinese geological magazine *Geology Report (Di Zhi Hui Bao)* published Ding's report on the *Bai Yun E Bo* ore body. But in additional remarks by the head of the Chinese Geology Survey Weng Wenhao wrote that: "the iron ore near the borderland has attracted national attention . . . We

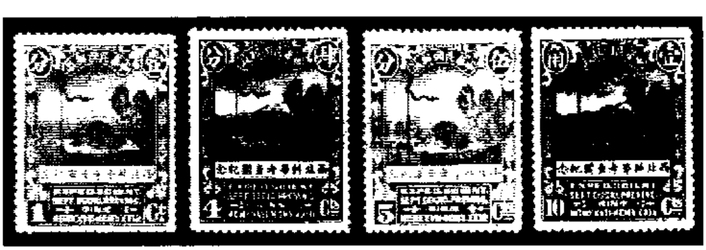


Figure 3. Souvenir stamps of the Survey.

can not [at this stage] estimate its reserves just on the basis of its surface area. We need further survey". But the CGS didn't in fact make any further survey in the area. There are two possible reasons: first, Weng doubted Ding's estimation of the size of the deposits; or, second, Weng wanted to avoid drawing Japanese attention to the ore, as the Japanese army had already occupied the northeastern part of China and *Bai Yun E Bo* was not far from the Japanese occupied area. (Subsequently the Japanese sent a geologist to survey the area of the *Bai Yun E Bo* iron ore when they occupied Beijing in the early 1940s.)

In 1952, three years after the People's Republic of China was established, the Government organized a large-scale geological survey to investigate the *Bai Yun E Bo* deposits and decided to construct a large integrated iron and steel works in the district. The factory began production in 1959 and Premier Zhou Enlai was present at the ceremony. Thereafter, a new city appeared at *Bai Yun E Bo*. In 1987, when the sixtieth anniversary of the discovery of the *Bai Yun E Bo* ore body was held, a statue of Ding Daoheng was erected in his honour.

3.2 The synthetic survey of mineral resources in Xinjiang

The Hedin Survey also stayed in Xinjiang for a long time, which gave further opportunity for the team's geologists to pay attention to mineral resources. Therefore, the reports of both of the Eastern and Western geologists included information about mineral resources, though they did their fieldwork severally.

Early in 1928, the expedition members arrived in Xinjiang and began their fieldwork. And the two Chinese geologists stayed in Xinjiang for a long time – Ding Daoheng for two years and Yuan Fuli for more than three years.

According to the Survey's agreement, the main task of the geologists was to conduct a survey of the region's stratigraphy and paleontology. But the two Chinese geologists paid much attention to the mineral resources, as there had been no previous survey of that kind in the region.

While in Xinjiang, Ding surveyed much of the southern part of the Province, looking for and finding a wide variety of mineral resources. After his survey work was completed, he wrote a report, *Records of Xingjiang's Mineral Resources (Xinjiang Kuang Chan Zhi Lue)*, which was published in 1931. The records included many kinds of mineral resources in the Province, such as petroleum, coal, iron, copper, gold, silver, lead, tin, jade, etc. Ding also published a map showing the distribution of mineral resources on the scale of 1:6,000,000 (see Fig. 4). The article was "the first paper resulting from a synthetic survey of mineral resources in Xinjiang".

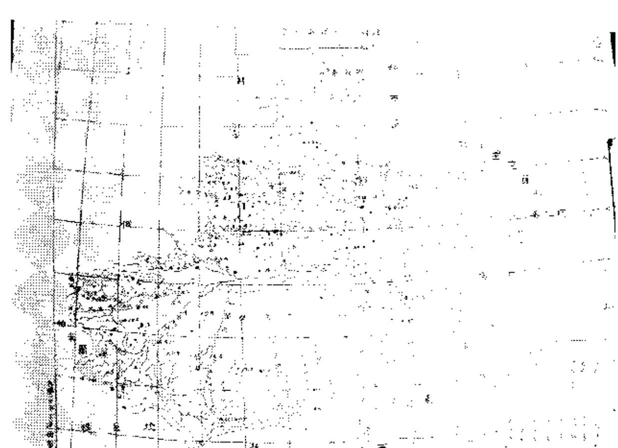


Figure 4. *The Map of Mineral Resources Distribution in Xinjiang* (Ding, 1931). The map shows the whole of Xinjiang. The Chinese characters at the top show the map's scale. The characters at the left give the date of compilation and the author's name. And the legend at the right shows the different mineral resources, with petroleum, gold, copper, coal, lead, iron, and some other materials being represented.

4. CONCLUSION: FOCAL POINTS OF THE MINERAL RESOURCES SURVEY AND THE REASONS

The Chinese investigators paid particular attention to coal and iron resources. They also considered the geological theory of mineral resources, as well as methods for their exploitation, their potential influence on the local economy, transport, and the best seasons for exploration. However, they paid rather little attention to petroleum, though there are abundant reserves in western China. Perhaps surprisingly, the Chinese geologists thought that oil deposits were mostly to be found in northwestern China and there was already some small-scale exploitation in this area. But it appears from the reports that there was only a cursory survey of the oilfield. So, why didn't they pay much attention to petroleum? We get some clues from Yuan's memoirs in the 1980s:

> When we arrived in Xinjiang in March 1928, we met with obstruction from the local government. They suspected that we went to Xinjiang for petroleum. And there were many rumours, such as that there was in the team a returned student from the United States who had agreed with the Americans to survey for oil exploitation (Yuan Fuli, 1983).

This may indicate a suspicion of foreign exploitation. Be that as it may, because of the special circumstances of the time and the special region, the mineral resources survey became one of the major achievements of the Sino-Swedish Scientific Expedition. The Chinese geologists paid much attention to commercially sifgnificant minerals even if the Westerners were not then interested.

Serving China through Science was a national slogan in China at that time and Chinese scientists at the time of the Survey believed that they should be doing something for their country. However, Xinjiang was controlled by warlords at that time and there were deep political, national, religious conflicts so the unsettled local political environment impeded mineral surveying.

We see that the development of Chinese geology in the twentieth century was intertwined with the social, political and economic environments of the times. We also find that the relationship between science and society was close during the crisis-ridden period of the Survey.

ACKNOWLEDGEMENTS

I thank David Oldroyd for his advice and assistance with English.

REFERENCES

Chinese Academic Association, 1928. Notes of Negotiations between Seven Hedin and Chinese Scholars. *Report of the Scientific Survey in Northwestern China* (in Chinese).

Ding D. 1931. Records of Mineral Resources in Xinjiang. *Geoscience (Di Xue Za Zhi)*, 4, 489-510 (in Chinese).

Ding D. 1933. Report on Bai Yun E Bo's Iron Ore. *Geology Report (Di Zhi Hui Bao)*, 23, 53-58 (in Chinese).

Geological Survey of the Ministry of Agriculture and Commerce, 1919. Records of Chinese Mineral Resources. *Special Journal of Geology (Di Zhi Zhuan Bao)*, B1, 238-243 (in Chinese).

Wang R. 2005. The Investigation and Exploitation of Northwestern China. *Transactions of Ningxia University (Humanities and Sociology) (Ningxia Da Xue Xue Bao)*, 27 (5), 11-16 (in Chinese).

Xie J. 1935. Chinese Petroleum. *Transaction of Geography (Di Li Xue Bao)*, 2(1), 11-20 (in Chinese).

Yuan F. 1983. The Sino-Swedish Scientific Cooperative Survey in the Northwest Part of China in the 1930s. *Chinese Data on Science and Technology (Zhong Guo Ke Ji Shi Liao)*, 4, 53-61 (in Chinese).

Zhang L. 2000. Review and Prospect of Chinese Geology in West Part of Tian Mountain. *Geology of Xinjiang (Xinjiang Di Zhi)*, 18 (3), 264-272 (in Chinese).

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

THE RUSSIANS IN MADRID, 1926-THE SPANIARDS IN MOSCOW, 1937: TWO IGC MEETINGS

Irena G. Malakhova

Department for the History of Geology, Vernadsky State Geological Museum, Russian Academy of Sciences,
Mokhovaya st. 11, bldg. 11, Moscow 125009, Russia.
malakhova@sgm.ru

Abstract. The 2010 Annual INHIGEO meeting in Spain was an occasion to remember two sessions of the International Geological Congress (IGC). The 14th IGC in Madrid (1926) was the first geological forum visited by representatives of a new state - the Union of Soviet Socialist Republics. Moscow welcomed the delegation of the Spanish Republicans in 1937. This time of great political events had an impact on science and society.

1. INTRODUCTION

The history of international geological congresses seems to be interesting on the threshold of the International Union of Geological Sciences 50th anniversary (2011) and 75 years since the 17th IGC in 2012.

Since the 1st IGC in Paris (1878) geologists have met every 3 or 4 years, and little by little worked out procedures, regulations and lexicon. International cooperation considerably ensured the progress of geosciences. Some tendencies of how geological sciences have developed can be traced through the history of the IGC. Giving a rostrum to host countries draws attention of the international society to geological studies of their regions. Congress excursions and direct contacts were the most attractive parts of international meetings.

The IGC schedule was altered by the WWI (1914-1918) and WWII (1939-1945). Political changes on the world map required economic support. Geology was to play a key role to meet demands for mineral resources. A section on economic geology (ore deposits) was introduced for the first time in the program of the 10th ICG in Mexico in 1906 (Congrès géologique international, 1907). The special three-volume monograph "Coal resources of the world" was prepared for the 12th IGC in Toronto (1913). The Russian delegation's activities were appreciable in this meeting (Fig. 1). Th. Tchernyshev, F. Loewinson-Lessing, V. Vernadsky entered the Council. J. Samojloff talked about studies on phosphates in Russia. His proposal to evaluate the world resources of phosphates was accepted in the 12th IGC (Congrès géologique international, 1913), and many countries began working on it. Results were reported only after the WWI.

2. THE 14TH IGC (MADRID, 1926)

The first after-war IGC took place in Brussels (Belgium) in 1922. The Congress accepted the official invitation of

Figure 1. The way to Canada – on a board of the 'Empress of Britain': sitting (from left) – J. Samojloff, F. Loewinson-Lessing, V. Vernadsky, Th. Tchernyshev; standing – M. Lyuboshinsky, V. Loewinson-Lessing.

Figure 3. Dmitri I. Mushketov.

Figure 2. The Congress hall in the Geological Institute of Spain, Madrid (1926).

the director of the Spanish Geological Survey (Geological Institute of Spain) C. Rubio y Muñoz (Puche et al., 2004).

Mineral resources of Spain have been known since the Roman Empire and that raised interest in European geologists. The Geological Survey of Spain was founded in 1849 (Ayala-Carcedo et al., 2005). Spain, as "a storage" of mineral deposits, could show either variety of natural resources or exploration results. The head of the Mining Council, C. Rubio, became the Congress president (Congrès géologique international, 1927, I).

The meeting of geologists in Belgium in 1922 was hold in absence of representatives from countries involved in the war conflict. Thus, no official invitation was sent to Russia, but four scientists attended the meeting on their own (Congrès géologique international, 1924, I). In this manner, the 14th IGC session was the first full-scale international forum after the First World War (Fig. 2). Madrid was the first city that welcomed geologists from the new state - the United State of Socialist Republics (USSR). Members of the USSR Academy of Sciences (Table 1), A. Karpinsky, F. Loewinson-Lessing, A. Pavlow, were recognized abroad. Future full members of the Academy, A. Zavaritsky and A. Borissiak, were introduced in Madrid. The director of the Fedorov Institute in Leningrad, A. Boldyrev, became known in Spain after his text-book was translated into Spanish - "Cristallografia" (1934).

D. Mushketov was a prominent Russian geologist during the 1920-1930s (Fig. 3). He was the head of the Mining Institute in Leningrad from 1918 to1926, and attended the 13th ICG with J. Samojloff in absence of the official Russian delegation. D. Mushketov came to Spain ranked director (1926-1929) of the National Geological Survey (Geological Committee).

The participants of the 14[th] ICG discussed the following issues: 1. World reserves of phosphates and pyrites; 2. Geology of the Mediterranean; 3. Cambrian and Silurian fauna ; 4. Geology of Africa and relationship with European geology; 5. Tertiary vertebrates ; 6. Hercynian folding; 7. Tertiary foraminifera; 8. Modern theories in metallogeny; 9. Vulcanizm; 10. Geophysics: pure & applied; 11. Miscellaneous (Congrès Géologique International, 1927-1928, I).

Name	Institution
Alexander P. Karpinsky (1847-1936) ancient President of the 14th IGC	U.S.S.R. Academy of Sciences (president)
Dmitri I. Mushketov (1882-1937) Vice-President of the 14th IGC	Geological Committee of Russia (director)
Anatoly K. Boldyrev (1883-1946)	Mining Institute, Geological Committee
Alexey A. Borissiak (1872-1944)	U.S.S.R. Academy of Sciences
Boris L. Issatchenko (1871-1948)	Institute for Hydrogeology
Elisabeth V. Jérémine E. (1879-1964)	Geological Laboratory, Sorbonne
Franz Yu. Loewinson-Lessing (1861-1939)	U.S.S.R. Academy of Sciences
Simeon F. Maliavkin (1876-1937)	Geological Committee
Pavel M. Nikiforov (1884-1944)	Institute for Applied Geophysics
Alexey P. Pavlow (1854-1929)	Moscow University
Maria V. Pavlow (1854-1938)	Moscow University
Alexander N. Zavaritsky A. (1884-1952)	Geological Committee

Table 1. The Soviet delegation in Madrid, 1926.

J. Samojloff's whises would come true - "World reserves of phosphates and pyrites" was the key topic in Madrid. His paper on sedimentology was announced in the program. But the scientist died in 1925 and results of collective work were reported by his disciples. S. Maliavkin presented a paper named "Phosphates deposits of the European Russia". A. Zavaritsky with a paper on the Ural pyrites was a speaker at the special sitting where C. Rubio reported the world resources of pyrites.

Soviet geologists were active on the geophysical section. D. Mushketov was the founder (1924) and director of the Institute for Applied Geophysics of the Mining Institute in Leningrad. His paper on geological, mining and geophysical explorations in Russia was discussed by R. Reinike, F. Kossmat, H. Stille, and Mushketov's colleague P. Nikiforov, who had prepared 3 communications. He talked about gravimetric and seismic methods of geological explorations, and showed a new seismograph and variometer (Congrès géologique international, 1927-1928, I).

D. Mushketov with a paper on tectonics of Turkestan and A. Pavlow with results from studies of Pliocene-Pleistocene continental deposits of Eastern Europe were among the speakers on the section 'Miscellaneous'.

The articles of A. Zavaritsky, P. Nikiforov (3), D. Mushketov (2), A. Pavlow and N.A. Grigorovitch-Beresovski (absent) (Note: On the Tertiary deposits of Dagestan - Irena Malahkhova) were published in the Congress proceedings (Congrès Géologique International, 1927-1928). Some Soviet geoscientists could not attend the Congress, but their abstracts were published in a special volume: on geology (A. Guerassimov) and tectonics (V. Rengarten) of the Caucasus, stratigraphy of the Carboniferous and Perm (N. Lebedew, N. Yakovlev) (Congreso geológico internacional, 1926).

The Spanish and Soviet geologists were elected in the Congress commissions (Table 2). Thanks to D. Mushketov the Commission on geothermy was renewed in Madrid. Its foundation was initiated by Th. Tchernyshev - head of the Russian delegation in the 10th IGC in Mexico (1906) (Congrès géologique international, 1907).

In Madrid D. Mushketov delivered an official message of the Soviet Government to undertake an engagement on the Spendiarov Prize (Congrès géologique international, 1927-1928, I). The IGC award was established during the 7th IGC in Saint-Petersburg (1897) and has been re-awarded since the 15th IGC in Pretoria (1929).

When they had to choose excursions, the Soviet geoscientists followed their own professional interests: Canary Islands (E. Jérémine), Sierra de Guadarrama (F. Loewinson-Lessing, A. & M. Pavlow), Aranjuez (F. Loewinson-Lessing, D. Mushketov), and Bilbao's Mines (A. Boldyrev, S. Maliavkin, A. Zavaritsky).

After Congress D. Mushketov published an article on Catalonian tectonics and established similarity of this volcanic region with East Turkestan. He emphasized the role the Spanish Congress played for geological exploration of the country and mentioned how perfect the organization of excursions was (Mushketov, 1931).

Commission	From Spain	From the U.S.S.R.
Carte Géologique Internationale du Monde	V. Kindelán A. Marín y Beltran de Lis	D. Mushketov W. Obrutchev
International Lexicon des Stratigraphie	J. Royo Gómez	A. Pavlow
Palaeontologia Universalis	J. Royo Gómez	A. Pavlow
Spendiarov Prize	C. Rubio y Muñoz	A. Karpinsky
Géophysique Appliquée	V. Kindelán J. Miláns del Bosch G. Sans Huelen	D. Mushketov P. Nikiforov

Table 2. The Spaniards and Russians – members of the 14th IGC Commissions.

3. FROM MADRID TO MOSCOW

In 1929 the South African Union was the host country of the 15th IGC. Only two Soviet representatives could come to Pretoria — D. Mushketov and N. Fedorovsky. It was D. Mushketov who announced the official proposal to hold the next IGC in the Soviet Union to celebrate the Geological Committee of Russia 50th anniversary (1882). Voting results was 33/23 for the USA (International Geological Congress, 1930). But the USSR would become elected 4 years later (Figs. 4 and 5). The prestige of geoscientists and the progress on geological studies in the Soviet Union were evident. The new Soviet state and its closed society did not enjoy a warm support

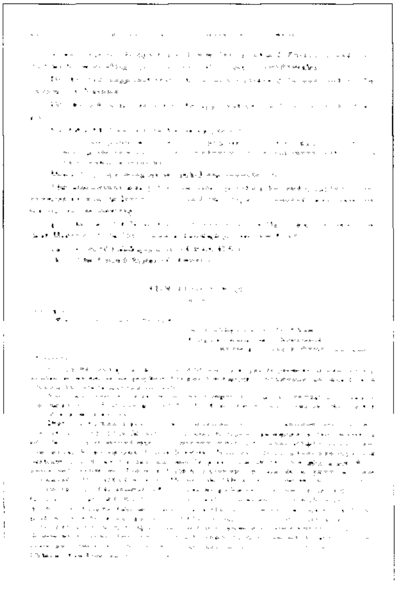


Figure 4. The Soviet offer (part I).

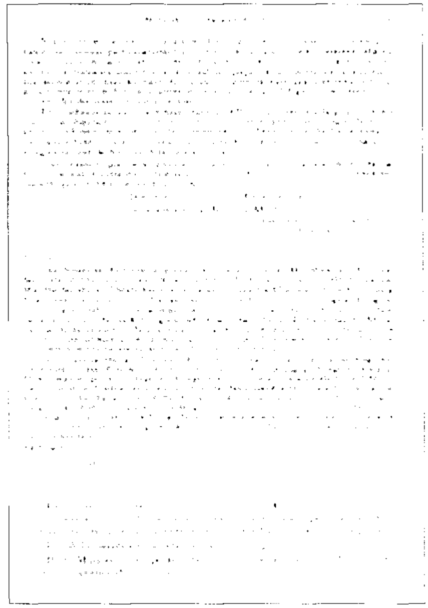


Figure 5. The Soviet offer (part II).

abroad, but the temptation of crossing the Soviet boundaries was too great. The final decision was made on the 16th ICG in Washington (1933). The Soviet invitation was repeated by a new player on the international geological scene - the head of the delegation academician, I. Gubkin (International geological congress, 1936, I).

The Soviet government did not permit D. Muchketov to visit the Congress in Washington ([Mushketov Dmitri Ivanovich], 1931-1934). His letter on June 10, 1933 was read in the meeting of the Commission on the Earth's crust. Insisting on new elections, he had worked out the program of the Commission activities: tectonic dictionary, history & bibliography of geotectonic theories, collective works on regional tectonics, and studies in Quaternary tectonics (International Geological Congress, 1936, I, p. 116). Even in his absence, D. Mushketov was elected the chairman of the Commission and his papers were published in the Congress proceedings. The General Secretary of the 16th IGC, W. Mendenhall, wrote to D. Mushketov that his "work in the South Africa was the main reason for the USSR election as the place of the 17th IGC. Such priority was recognized thanks to your activities in Pretoria and high scientific prestige" (Vyalov, 1985, pp. 13-14).

In 1930s the Soviet Union finished reforms that affected geosciences. The generation of Russian geologists was replaced. The Academy of Sciences moved to Moscow with the affiliation of new research institutes. The reform of geological education resulted in an army of specialists working all over the country. The Geological Committee was fully reorganized. D. Mushketov lost his position while he was on the 15th IGC in Pretoria. I. Gubkin took this place.

The 17th IGC could have been Mushketov's triumph, but his life ended tragically. Year 1937 is the 'blood date' in our history - the time of the Great Terror. About 70 organizers and participants of the Moscow Congress were repressed, and 13 of them were shot (Repressed geologists, 1999). D. Mushketov was arrested three weeks before the Congress opening. He was prosecuted for counter-revolution activity and espionage and was shot on February 18th, 1938 (Letter from the Supreme Court, 1962).

But the propaganda the international scientific meeting was making was so great that some discharged geologists were included in the list of participants and two prisoners (former leaders of the Geological Committee, N. Tikhonovich and V. Kotul'sky) even visited sittings with a guard (Repressed geologists, 1999).

Figure 6. - A speech of I. Gubkin (1871-1939) on the party

4. THE 17TH IGC (MOSCOW, 1937)

Since the October revolt of the year 1917 the new state had expired political isolation. This process had been in progress owing to the home policy of the Soviet Union. This political isolation led to a scientific one. In 1937 the USSR opened its boundaries for members of the international geological society to prove the achievements of its army of well-trained explorers.

238 scientists from 39 countries came to Moscow. The total number of participants was 949 (International Geological Congress, I, 1939). Political events in Europe affected the imposing appearance of the Congress. Neither Germans, nor Italians visited Moscow. Traditional Russian hospitality and perfect organization had partially eliminated those negative effects (Fig. 6). The 17th IGC opened in the Great Hall of the Conservatory in Moscow (Fig. 7) and I. Gubkin was elected the Congress president.

Figure 7. The Great Hall of the Moscow Conservatorium

The technical program included the next Sections: 1. The petroleum problem and the petroleum resources of the world; 2. Geology of coal fields; 3. The Pre-Cambrian and mineral deposits in the region of its development; 4. The Permian System and its stratigraphic position; 5. Correlation of tectonic processes, magmatic formations and ore deposits; 6. Tectonics of Asia; 7. Problems of geochemistry; 8. Geophysical methods in Geology; 9. Geology of the Arctic regions; 10. Miscellaneous papers; 11. Symposium on Paleozoic and Pre-Cambrian climates (International Geological Congress, I, 1939).

Soviet geologists made great progress in coal and oil geology. 'Oil topic' had appeared in the IGC program since the meeting in Pretoria (International Geological Congress, 1930). I. Gubkin had the reputation of being a leader in petroleum geology in the USSR. He was a convener of the section "Geology of petroleum" in the 16th IGC in Washington (International geological congress, 1936). His paper named "Petroleum resources of the world" opened the first general meeting of the 17th IGC. 3 communications of I. Gubkin were reported in the section on petroleum geology (International geological congress, 1939, I).

Comparing technical sessions in Madrid and in Moscow the next changes could be traced. Three topics of the Madrid Congress were pooled in Moscow. Traditional European discussion on the Cambrian and Tertiary stratigraphy was nationally coloured in Russia. Geographical position predetermined regional interests. While geology of the Mediterranean and Africa were discussed in Madrid, Asia and the Arctic region were the points of interest in Moscow. Geophysical sections were worked on both sessions. The Moscow program met demands of progress of geochemistry in the world.

The Madrid Congress provoked activity of Spanish geologists on the IGC meetings. Spain went through the Civil War (1936-1939) and it disrupted the country. The door to the USSR was open only to the Republicans officially supported by the Soviet government. Their visit to Moscow gave an important political feature to the international meeting.

Eight Spanish geoscientists intended to participate in the 17th IGC but only four of them attended the meeting (Table 3).

Name	Institution
José Royo Gómez (1895-1961)	Geological Survey of Spain (director)
Rafael Candel i Vila (1903-1976)	University of Barcelona
Gabriel Martín Cardoso (1896-1954)	Museum of Natural History, Madrid
Vicente Sos Baynat (1895-1992)	Instituto de Castellón (director)

Table 3. The Spanish delegation in Moscow, 1937.

J. Royo Gómez, V. Sos Baynat and R. Candel i Vila welcomed Soviet geoscientists in Spain in 1926. A participant of the 14th IGC M. San Miguel de la Cámara announced a paper on eruptive Mesozoic rocks of Spain for the section "Correlation of Tectonic Processes, Magmatic Formations and Ore Deposits", but he did not attended. V. Sos Baynat presented a paper "On geology of the Western Mediterranean" on the section "Tectonics of Asia" — the most popular topic with 20 papers on theoretical and regional geotectonics. Symposium of paleoclimates was requested in Pretoria (1929) and became a topic of special interest for foreign participants with discussions on Late Proterozoic and Paleozoic climates. The paper named «Paleontological occurrences in environs of Madrid» by J. Royo Gómez was included in the program. G. Cardoso was a speaker on the section 'Miscellaneous' with a paper named «Granites of the Province of Galicia, Spain». The articles of V. Sos Baynat and J. Royo Gómez were published in the Congress proceedings.

The Spaniards and the Russians were elected in the next commissions of the 17th IGC (Table 4).

The program of the pre-Congress excursions included a trip to Leningrad. The Fedorov Institute held a special meeting where two participants of the 14th IGC met. A. Boldyrev, director of the Institute, made a presentation on goniometric and roentgenometric methods in crystallography. His Spanish colleague R. Candel i Vila traced the history of Mineralogy and Crystallography in Spain. The State Library in Moscow has a copy of his travel account signed: "For the Lenin Library from the author (Barcelona, 10\VIII\1938)" (Candel i Vila, 1938).

Twenty five excursions were offered to the Congress members to prove the natural variety of the country and its economic and scientific achievements. J. Royo Gómez and V. Sos Baynat took advantage of this chance and made a long trip from the Urals to Caucasus (Fig. 8). This journey was not long ago described in detail (Montero, 2004).

Commission	From the U.S.S.R.	From Spain
International Stratigraphic Lexicon	A. Borissiak	R. Madariaga
International Geological Maps (World & Europe)	A. Arkhangelsky, I. Gubkin	E. Dupuy de Lôme
Fossil Man (national subcommissions)	Academy of Sciences of the U.S.S.R.	J. Royo Gómez (Chairman), V. Sos Baynat (Secretary)
Earth's Crust	N. Shatsky, Ya. Edelstein	J. Marcet-Riba
Geophysics & Geothermy	P. Nikiforov (Chairman), O. Schmidt, A. Arkhangelsky	J. Siñeriz, V. Inglada Ors

Table 4. The Russians and Spaniards – members of the 17th IGC Commissions.

There were twelve speeches in the closing meeting of the 17th IGC. Heads of delegations shared their impressions: Ph. Smith (USA), E. Bailey (England), Ch. Jacob (France), J. Royo Gómez (Spain), P. Fourmarier (Belgium), Nadjib Ula (Afghanistan), E. Bruce (Canada), L. Picard (Palestine), Th. Vogt (Norway), S. Haughton (South Afr. Union), P. Bakalov (Bulgaria), I. Gubkin (USSR).

J. Royo Gómez said in his fervent speech: "We had a real opportunity to appraise the development of Geology, Petrology, Mineralogy and Crystallography in Russia initiated by the works of Karpinsky and Fedorov. The progress in geosciences not only was stopped in the Soviet Union but *vice versa* was precipitated owing to the efforts of the Soviet government and scientists [...] The Spanish Republicans feel even more emotional the scientific effect of the Congress [...] since our first steps in the Soviet Union we have met friendship and support of authorities, colleagues and all people" (International Geological Congress, 1939, I, p. 155-157).

Meanwhile, the visit to the USSR had serious consequences for some members of the Spanish delegation. J. Royo Gómez, extremely active in politics (Camarasa and Català, 2009), visited France in 1939 and sent an application for a Soviet visa. He was permitted to enter the country for research work in institutions of the Academy of Sciences (On the permission to enter the USSR, 2000). The same year J. Royo Gómez moved to Colombia (Montero, 2004). His colleague in the Museum of Natural History in Madrid, G. Martín Cardoso, was pressured in Franco's time (Ordóñez and La Iglesia, 1996). Rafael Candel i Vila, who has lived in France since 1948, was also pressured (Candel i Vila, 2006).

Figure 8. The Urals excursion

6. CONCLUSIONS

The years of two IGC - 1926 & 1937 - have marked the inter-war period. For a short time Spain and Russia became the "hot continental margins" of the process that turned the world into catastrophe.

Political ambitions required support, and Geology was to meet economic demands. Progress in economic geology was evident, and scientific results were discussed in the IGC meetings. Mineral resources had increased the war potential of the parties in the WWII.

While the 14th IGC raised hopes in the international geological society, members of the Moscow meeting could feel political opposition in Europe and isolation of the Soviet Union. It had negative consequences for international cooperation in Geology and for geoscientists' lives.

ACKNOWLEDGEMENTS

I thank Prof. Dr. Octavio Puche Riart and Prof. Dr. Jesús Ignasi Català Gorgues for their interest to the topic and copies of publications about Spanish history and geoscientists.

REFERENCES

Ayala-Carcedo, F.J., Perejón, A., Jordá, L. and Puche, O. 2005. The XVI International Geological Congress of 1926 in Spain. *Episodes,* 28 (1), 42-47.

Camarasa, J,M. and Català J.I. 2009. La diàspora i l'exili interior. In : Vernet, Parés, J.R. (ed.), *La Ciència en la Història dels Països Catalans.* Universidad de Valencia, Valencia, 829-852.

Candel i Vila, R. 1938. El XVIIè Congrés Geològic Internacional. Extrait d'ARXIUS d l'Escola Superior d'Agricultura. *Nova Sèrie,* IV (I), 189-224.

[Rafael] Candel i Vila. In: Societat Catalana de Geografia. 2006. http://scg.iec.cat/Scg7/Scg72/S720012a.htm (02.05.2010)

Congrès géologique international 1907. *Comptes rendu de la Xème session, Mexico, 1906. 1.* Imprenta y fototipia de la Secretaria de Fomento, Mexico, X, 699 pp.

Congrès géologique international 1914. *Compte rendu de la XIIe Session, Canada, 1913.* Imprimerie du gouvernement, Ottawa, 1034 pp.

Congrès géologique international 1924. *Comptes rendu de la XIII Session, en Belgique, 1922 I.* Imp. H. Vaillant-Carmanne, Liege, VII, 595 pp.

Congrès géologique international 1927-1928. *Comptes rendus de la XIVe Session, en Espagne, 1926.* Gráficas Reunidas, S.A., Madrid, Fasc. 1 (VI), 323 pp.

Congreso geológico internacional 1926. *XIV session. España. Resumen de las comunicaciones anunciadas.* Gráficas Reunidas, S.A., Madrid, 235 pp.

International geological congress 1930. *South Africa, 1929. Compte Rendu* I. Wallachs, Ltd., Pretoria, 314 pp.

International geological congress 1936. *Report of the XVI Session, United States of America 1933* 1-2. U.S. Government Printing Office, Washington. VII, 702 pp.

International geological congress 1939. *The USSR, 1937. Proceedings.* I. GONTI, Moscow, 649 pp. (in Russian)

Letter from the Supreme Court of the U.S.S.R. to the Chairman of the Commission on the Geological Study of the U.S.S.R. Professor V.V. Tikhomirov, 1962. Archive of the Department for the History of Geology, Vernadsky State Geological Museum, Russian Academy of Sciences, Moscow, 1 pp. (in Russian)

Montero, Á. 2004. El viaje a Rusia en 1937 de José Royo Gómez y Vicente Sos Baynat. In : Truyols, J., Diéguez, C. and Perejón, A. (eds.), *Homenaje a José Royo Gómez. 1895-1961.* Consell Valencià de Cultura, Valencia, 243-251.

[Mushketov Dmitri Ivanovich] Documents on the trip of D.I. Mushketov to the 16th International Geological Congress in USA in 1933 which did not took place. 1931-1934. In: The Mushketovs Archive. The Archive of the State Public Library, Saint-Petersbourg. Fund. 503. File 620. 48 pp. (in Russian)

Mushketov, D. 1931. The role and importance of the Catalan volcanic region in tectonic conception of the West Mediterranean. *Bulletin of the Geological and Prospecting Service of the USSR L*, (25), 406-409. (in Russian).

On the permission for José Royo Gómez to enter the USSR. March 23, 1939, 2000. *The Academy of Sciences in resolutions of the Political Bureau of the Central Committee of the Russian Communist Party (of Bolsheviks) – All-Russian Communist Party (of Bolsheviks) – Communist Party of the Soviet Union. 1922-1991.* Russian Political Enciclopaedia, Moscow, 271-272. (in Russian).

Ordóñez, S. and La Iglesia, A. 1996. Gabriel Martín Cardoso (1896-1954): el nacimiento en España de la determinación de estructuras cristalinas de minerales mediante difracción de rayos X. *Geogaceta*, 20 (6), 1426-1428.

Puche Riart, O., Ayala Carcedo, F.J., Jordá Bordehore, L. and Perejón, A. 2004. Apuntes biográficos de César Rubio y Muñoz (Cáceres, 1858-Madrid, 1931) Presidente del XIV Congreso Geológico Internacional (Madrid, 1926). *Llull*, 27, 465-473.

Repressed geologists, 3th ed., 1999. *Ministry of Natural Resources and Ecology of the Russian Federation, Federal State Unitary Enterprise 'A.P. Karpinsky Russian Geological Research Institute.* Russian Geological Society, Moscow–Saint Petersburg, 452 pp. (in Russian).

Vyalov, O.S. 1985. *All I know about D.I. Mushketov – a remarkable scientist, outstanding organizer and teacher (to the 100th commemoration).* Archive of the Department for the History of Geology, Vernadsky State Geological Museum, Russian Academy of Sciences, Moscow, 16 pp. (in Russian).

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

GEOLOGICAL AND MINERALOGICAL TOUR THROUGH MEDINACELI COUNTY (SORIA, SPAIN): FROM MEDINACELI TO VELILLA DE MEDINACELI AND SOMAÉN

Josep M. Mata-Perelló

Departamento de Ingeniería Minera y Recursos Naturales de la UPC (Universitat Politècnica de Catalunya)
Av. Bases de Manresa, 61–73, 08242 Manresa, Spain.
mata@emrn.upc.edu, jm.mata@cdi.cat, rocpetrus@gmail.com

Abstract. We present a geological and mineralogical tour that will go through certain parts of the Land of Medinaceli in Soria province, in the southern sectors. In fact, we will look over the towns of Medina, Salinas de Medinaceli, Jubera, Longares, Velilla de Medinaceli and Somaén, all of them almost bordering with the province of Guadalajara. On this tour you will visit various mineralizations, some of which once operated (such as the iron ores of Jubera and Somaén). In this case, we will also observe the ferruginous mineralization filling karstic cavities, located in the municipality of Somaén, close to Velilla de Medinaceli. At this visit we can see mineralizations of goethite (limonite) and hematite. On the one hand, we will check out the crystallization of aragonite, laying among Triassic materials (Keuper), near Velilla de Medinaceli. These are known as pseudohexagonal twins, with concave angles, typical of this locality. On the other hand, we will visit the saltworks of Medinaceli, located among Triassic outcrops of Keuper, at the foot of this important historic city. These saltworks lay among outcrops of clay materials and gypsum from the Upper Triassic. Moreover, in this journey several observations will be made on materials of the Iberian Mesozoic, and they shall be made through the whole length of this route. In this manner, they will emerge from materials of Triassic, Jurassic and Cretaceous. Within this context, there is an angular unconformity between these materials and the overlying Cenozoic, near Somaén and Jubera.

1. INTRODUCTION

On this occasion, there will be a geological and mineralogical tour, developing entirely in the county of Medinaceli, province of Soria (Castilla y León), in the southern part of the above mentioned Spanish province.

This trip will run in an unique way through a single geologic unit part of the Iberian Peninsula, named the Iberian Range, and more specific, the "Rama Castellana". Thus, we will basically find outcrops of Mesozoic material, partly covered by Eocene materials.

Referring to the situation of the rest of the region abovementioned, most of it is located within the "Rama Castellana" of the Iberian Range. However, the eastern tip of Tierra de Medinaceli is within the Almazán Depression, although we will not visit this area in this geologic tour.

2. MAIN OBJECTIVES.

The main objectives to be achieved with this geological and mineralogical journey, can be specified in terms of:

1. Study of the structure of the Iberian Range, between Medinaceli and Somaén - both within the region of Tierra de Medinaceli. Thus, we will only enter the so-called "Rama Castellana" of the Iberian Range in this tour.
2. Survey and observation of the Mesozoic materials that constitute the Iberian Range, and more specifically the Triassic, Jurassic and Cretaceous materials which form the basement of this Range - only in the locations this tour goes through.
3. At the same time, we will examine the Tertiary cover of the Iberian Range, which we will mainly find between the towns of Velilla de Medinaceli and Somaén.
4. Study and appreciation of different mineralizations along this route, with the following order:
   4A) mineralization in saltworks related to Triassic materials (Keuper), with an evaporitic origin. This mineralization can be observed from the town of Salinas de Medinaceli.
   4B) aragonite diagenetic mineralization in the vicinity of Velilla de Medinaceli, in all cases within the "Rama Castellana" of the Iberian Range.
   4C) concentrations of ferruginous ochers, linked to mineralizations of karstic cavity filling. We will also see these concentrations around Velilla de Medinaceli and Jubera.
5. Description of the exploitations of geological resources related to the abovementioned mineralization, especially those of halite and iron ocher.
6. Observation, if that is the case, of the restorations made to mitigate the impacts from mining activities. If not, we could also notice natural restoration.
7. Observation of elements related with Geological Heritage. In this section, some GPI (Geological Points of Interest) such as aragonite crystallizations in Velilla de Medinaceli, the mineralization of karstic cavity filling of Somaén or Jubera, or the Mesozoic —Cenozoic angular unconformity of Jubera— Somaén, among other places, are included.
8. Observation of the elements related to the Mining Heritage. In this section, some PIMH (Points of Interest Mining Heritage) as the saltworks of Salinas de Medinaceli or ocher holdings in Somaén, among other places, are included.

3. BACKGROUND

There is no record of the existence of geological and mineralogical routes that pass through the same places this tour does. However, there is a work (Mata-Perelló, 1995) which partly agrees with this, at least in the main paths of travel. As for the general geological features, there is no knowledge of the existence of work dedicated to these lands but the publication IGME (1972), to which we refer below. Regarding the mineralizations that we will see along the route, we refer to another work, particularly in Mata-Perelló (1990). All these publications, as well as others, are listed in alphabetical order in the chapter labeled "References".

Figure 1. General view of the salines.

4. GENERAL TOUR ITINERARY

This short route will run entirely along the county of Medinaceli. Thus, it will start in the town of Medinaceli, where we will do the initial stop of this tour. Then, we will go through a short rural path to end up in the surroundings of the town of Salinas de Medinaceli, where we will make a stop at the saltworks the town is named under. Even though we will go to the saltworks, we will be able to observe them from the first stop. After that, the journey will return back to Medinaceli, and we will go to the nearby towns of Longares and Jubera from there, stopping near the latter locality. Once we stop in Jubera, the tour will move towards Velilla de Medinaceli in order to make two new stops, one just before arriving at this town, and the other at its boundary with the town of Somaén. Finally, the tour will head to Somaén, where its itinerary will conclude after making one last stop in the vicinity of this village.

5. ITINERARY

As trips are normally structured, this itinerary is made out of a series of stops. In each of these stops we will make a brief comment - geological or mineralogical. In each case we will indicate, between parentheses, the number of the topographic sheet (1:50,000 scale, National Cartographic Institute and the Army Geographical Service). In this short tour, we will only use one sheet - to be more specific, sheet number 435 (or Arcos de Jalón). The list and description of the different stops are:

5.1 Stop 1. Roman Arch of Medinaceli (Medinaceli, County of Medinaceli, Province of Soria)

The route begins in an interesting historic place, next to the Roman arch of Medinaceli, located in the south of the town. From here, you can enjoy a good view of the valley at the foot of Medinaceli. It was excavated by the young Jalón River between the soft materials of Keuper, which are clearly distinguishable due to its reddish color. Indeed, Medinaceli is an interesting strategic position because of its location on a hill over the valley of the Jalón River.

5.2 Stop 2. Saltworks (Salinas de Medinaceli, County of Medinaceli, Province of Soria)

From the last stop, we will go down to the neighborhood next to the N-II, where we must go to the nearby town of Salinas de Medinaceli in order to reach the location of this stop. This stop is located next to the access road to the town, shortly before arriving to the town - about 4 km from the previous stop. In this case, we have been traveling between chalky and clay levels of Keuper (Upper Triassic), which form a large outcrop located at the foot of Medina, as we would have seen in the previous stop.

We will often see halite between levels of gypsum (Fig. 1). Due to groundwater movement between these materials, halite dissolves easily, resulting in the formation of salt water. Thus, we can observe salt efflo-

Figure 2. Mineralization of the Ocher mines of Las Lomas.

rescences in springs, related to water evaporation. These salt waters are collected in a series of bases, in which water evaporates leaving a salt residue.

5.3 Stop 3. Ocher mine of Las Lomas, (Jubera, County of Medinaceli, Province of Soria)

After the previous stop, it is necessary to go back to Medinaceli, and then continue through the N-II, heading east (to Zaragoza), following the old road along the Jalón River. This road passes by Lodares first and by Jubera second.

From this last town, we will take the upward path that leads to the old ocher mine of Las Lomas, below the motorway -10 km from the previous stop.

On this tour, we will exclusively drive by Mesozoic materials of the "Rama Castellana" of the Iberian Range. These materials belong to Triassic (Keuper) – more precisely to Supra-Keuper.

We can observe ferruginous concentrations (Fig.2), very terreous, located at the contact line between calcareous levels of Supra-Keuper, and others belonging to Eocene. In this manner, among the present iron ore (all oxidized), it has to be mentioned the hematite (always very dirty) and goethite (very terreous and with limonite). On the other hand, there are also indications of lepidocrocite (such as goethite: terreous and limonite) as well as siderotil. Finally, notice that this is a ferruginous mineralization associated with filling of karstic cavities in Mesozoic limestones.

5.4 Stop 4. Velilla de Medinaceli road (Velilla de Medinaceli, County of Medinaceli, Province of Soria)

In this stop, we will go first to the N-II road heading east, back to the start of the road to Velilla de Medinaceli. After taking this road, the stop is at about 2 km from there – 5 km from the previous stop.

Throughout this journey, despite the carbonate outcrops mentioned in the previous stop, the materials belong exclusively to Keuper. In this stop there is an interesting outcrop with abundant big aragonite crystals, but not very well crystallized. Often they show pineapple-like forms.

In this location, aragonite crystallizes in pseudohexagonal twins but generally concave. This gives them an appearance of stars, giving them some instability, so they are eroded much more easily than common.

5.5 Stop 5. Ocher iron mine of Somaén (Somaén and Velilla de Medinaceli, County of Medinaceli, Province of Soria)

From the previous stop, continue to Velilla de Medinaceli, but at a short distance from the outcrop there is a road on the left. This road leads to the nearby iron mines of Somaén (Fig. 3). To get there, drive for about 2 kms from the previous stop.

These mines are located on a mineralization related to filling karstic cavities, located at the contact line between levels of Supra-Keuper with others belonging to Eocene.

Figure 3. General view of the Somaén mine.

Figure 4. View of the mineralizations of the Somaén mine.

Figure 5. View of the galleries open through the iron oxides.

Figure 6. View of the karstic mineralizations.

Among the existing iron minerals, we must make special mention of goethite (limonite), with an intense and beautiful yellow color. Hematite is also present - very abundant and terreous.

In the existing galleries of this mine, especially in the one located to the right (Fig. 4), the mineralization can be perfectly observed filling karstic cavities (Fig. 5, 6). Thus, within this gallery there are fallen blocks, clay varves and ochers. These materials are usually covered with Mesozoic material.

Furthermore, from this place (looking to the NW), an interesting angular unconformity can be observed (Fig. 7). It is located between Mesozoic and Cenozoic materials. The former, of Jurassic age, are folded, while the latter, of Eocene age, are in subhorizontal position.

5.6 Stop 6. Somaén (Somaén, County of Medinaceli, Province of Soria)

From the previous stop, you have to make a brief tour to get to the town of Somaén, where we will make our last stop, just before entering the village - 5 km from Stop 5.

Figure 7. Angular unconformity between Mesozoic–Cenozoic in Jubera – Somaén.

On this tour, we will initially go through Keuper materials (mentioned in the previous stop) and then limestone belonging to Upper Keuper, eroded by the Jalón River, forming a beautiful gorge. Above these materials, we find Eocene detrital levels, which can be seen now at the area around the town of Somaén.

REFERENCES

IGME 1972. *Mapa Geológico de España a escala 1:200.000 (Síntesis de la cartografía existente). Hoja y Memoria nº 20, Soria.* Instituto Geológico y Minero de España, Madrid

Mata-Perelló, J.M. 1990. Inventario mineralógico de la Tierra de Medinaceli. *Revista Cantil,* 32, 26 pp.

Mata-Perelló, J.M. 1995. *Apuntes para un itinerario geológico-mineralógico por las provincias de Zaragoza, La Rioja y Soria.* Inedit Report, Manresa, 10 pp.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

HISTORY OF URANIUM AND NUCLEAR POLICY IN ITALY (1946-1965)

Andrea Candela

Dipartimento di Informatica e Comunicazione, Università degli Studi dell'Insubria, via Mazzini 5, 21100 Varese, Italy.
andrea.candela@uninsubria.it

Abstract. In 1952, within CNR (National Research Council), National Committee for Nuclear Research (CNRN) was founded in Italy, with the main purpose of acquiring and developing knowledge about peaceful applications of nuclear energy. In 1960, CNRN became a public self-governing institution, separated from CNR and changing the name into CNEN (National Committee for Nuclear Energy). During the first period of establishment, CNEN policy choices undoubtedly reflected optimism and triumphalism followed by the first United Nations Conference on peaceful use of nuclear power, held in Geneva in 1955. The huge interest towards different nuclear applications was certainly driven by strategic needs related to industrial and economic development of industrialized countries. At the beginning of the "industrial atomic age", nuclear industry was surely an instrument of technological "transfer" and innovation; it didn't represent an alternative to fossil fuels. Mining explorations were among the earlier activities undertaken in the CNRN foundation, mainly since 1961. A regional scale geochemical prospecting reconnaissance for uranium in several alpine regions and in different part of Central-Southern Italy was realized. These explorations represented undoubtedly an effort to manage an energy policy not entirely dependent on the international context and raw materials imports. Considering this historical outlook, the paper will try to trace the initial stages of uranium policy and studies in Italy. An interest that led to open a university teaching in "Geology of Uranium" at the Polytechnic School of Milan and to establish a scientific and technical discipline with its own handbooks, reviews and popular publications.

1. INTRODUCTION: GEOPOLITICS OF URANIUM AND HISTORICAL CONTEXT

At the beginning of the "industrial atomic age", after 1946, several restrictions regarding nuclear field were imposed on Italy, ex-belligerent and loser Country; without ignoring that nuclear power was also strictly protected by military secrecy in different States. Technological exchanges and transfers were not conceivable, even in the countries of the coalition of North Atlantic Treaty (Nato, 1949). Difficulties in order to provide uranium provisions were considerable: the localized stocks of ore, mainly coming from Congo, Canada and Australia, made national and submitted safety rules like banning of exportations and trade. Thus, the private mining companies, in many different countries such as United States, France, Great Britain, Canada, Soviet Union, could not seek uranium metals independently. It was only allowed to State Geological Surveys (Steinert, 1959). During the 1950's, the international geopolitical context gradually changed. Owing to the failure of Harry Truman's policy (Hobsbawm, 1997), revealed by the speed with which U.S.S.R. equipped itself with nuclear weapons, and after the progressive erosion of U.S. monopoly in nuclear technology, the President Dwight Eisenhower, took part in the General Assembly of United Nations in 1953, launched "Atoms for Peace" programme: United States would have made available to anyone knowledge on peaceful uses of nuclear power. On the other hand,

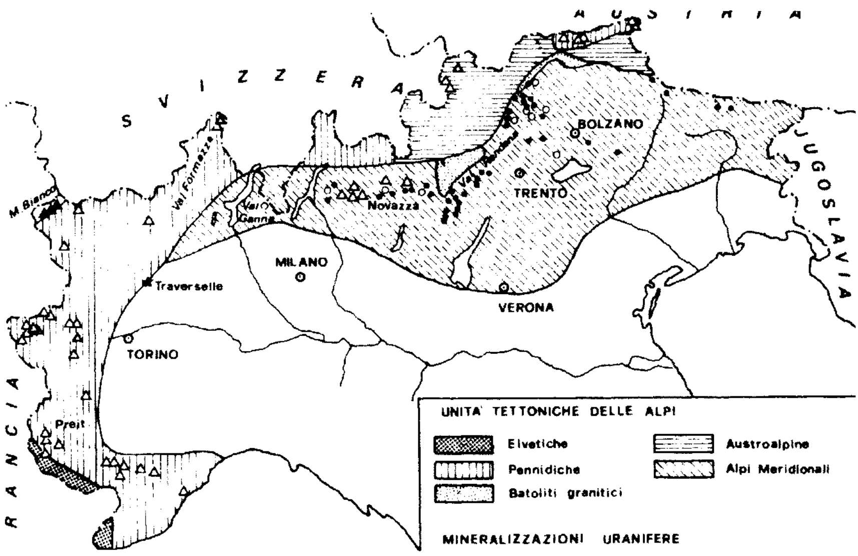


Figure 1. Uranium mineralizations of the Alps. Legend: ○ hydrothermal deposits of Permian volcanic rocks; ● stratiform epigenetic deposits of Permian sandstones; Δ metamorphic remobilization of pre-existing deposits in Permo-Triassic sediments; ▲ veins of Mont Blanc granite (De Vivo and Ippolito, 1984).

any other country should have abandoned the development of atomic arsenals. It was necessary to give up an energy policy of secrecy and to undertake a policy of transparency, negotiation and international cooperation. Undoubtedly United States aimed to keep a check on reactors technology and demand for uranium (Hewlett and Holl, 1989). The Atomic Energy Act of 1954 (Paoloni, 1992), that liberalized nuclear activities, and the institution of the International Atomic Energy Agency followed (1957). After the United States Atomic Energy Commission (Usaec), created in 1946 (Hewlett and Anderson, 1962; Hewlett and Duncan, 1969), and the French Commissariat à l'énergie atomique, founded in 1945, one of the most important European committee rose: in 1954 the United Kingdom Atomic Energy Agency was established (Curli, 2000). Consequently the private companies were allowed to build nuclear power plants and manage the whole fuel cycle, including wastes (Paoloni, 1992). Furthermore, at the end of the 1950's, after the military invasion of Suez Canal by British, French and Israeli armies in 1956, and the subsequent reduction of the middle-eastern petroleum exportations, nuclear power was seen as possible solution to any energy problem.

In this historical overview, which is described briefly, during 1952, within National Research Council (CNR – Consiglio Nazionale delle Ricerche), National Committee for Nuclear Research (CNRN – Comitato Nazionale per le Ricerche Nucleari) was founded in Italy, with the main purpose of acquiring and developing knowledge about peaceful applications of atomic energy, especially in biological and physical sciences and in agricultural activities. Nevertheless, it should not be ignored that the first attempt to create an Italian reactor, independently by any international relationship, can be attributed to the private sector of the "Information, studies and experience Centre" (Cise – Centro informazioni, studi ed esperienze), created in 1946 as a result of the actions taken by some big industrial groups, as Edison - the major Italian commercial electric company - Montecatini and SADE, with the scientific expertise of some young researchers of the State University of Milan, led by the Italian physicist Giuseppe Bolla (Silvestri, 1968; Zaninelli, 1996; Curli, 2000).

Subsequently, different engineers from Cise joined Nuclit, a private company financed by Government, whose main task was to establish the first Italian research reactor in Lombardy, near Ispra on the Eastern side of Lake Maggiore (Northern Italy). However, in 1956 the National Committee for Nuclear Research decided to buy an American reactor, working with enriched uranium, to gain experience in the field of nuclear energy production in Ispra. This disagreed with Cise strategies, which tried to develop autonomous industrial skills. The technological ambitions of Nuclit and Cise fell permanently in 1959, when the Lombard research Centre was handed over to the European Atomic Energy Community (Euratom). During the following years, the research activities of the Cise will go on with development of an Italian self-sufficient nuclear line production, by means of different projects (Eurex, Raptus, Pro and U-Th cycle), but without any success (Ippolito, 1965; Silvestri, 1968).

In 1960, the Committee became a public self-governing institution, separated from CNR and changing the name into National Committee for Nuclear Energy (CNEN – Comitato Nazionale per l'Energia Nucleare). In that way, the Country tried to develop its own know-how. In the first period of establishment, CNEN policy choices undoubtedly reflected optimism and triumphalism followed by the first United Nations Conference on peaceful use of nuclear power, held in Geneva in 1955 (Paoloni, 1992). It worked in close connection with industry for planning and realizing the nuclear power plants and the necessary technological infrastructures for fuel cycle. The new Committee was chaired by the Minister of Industry, which was governed by a managing board with an executive body, represented by the general-secretary, whose activity was supervised by a Government Commission. The Italian engineer Felice Ippolito (1915-1997) was elected to CNEN's secretariat.

In the new political view of those years, there wasn't a real competition between nuclear energy and fossil fuels; in fact, the huge interest towards different nuclear applications was certainly driven by strategic needs related to industrial and economic development of industrialized countries (OEEC – Organization for European Economic Cooperation). At the beginning of the "industrial atomic age", nuclear industry was surely an instrument of technological "transfer" and innovation; it didn't strictly represent an alternative to fossil fuels. The uranium fission offered a new energy resource, potentially unlimited, capable of increasing and emancipating Western economies, among all the European ones. They were "the roaring years of the atomic energy", as Bertrand Goldschmidt (1962) described them. The priority was the need to feed the increasing energy demand, produced by the Western "economic boom". Between 1950-1965, the Western European energy net imports made tenfold, while its energy dependence grew from 7,9% to 51,2%, particularly in oil imports (Hassan and Duncan, 1994; Curli, 2000). Thus, the initial projects in nuclear civil uses weren't in direct competition with oil companies. At first they strove to satisfy the energy security needs, pursuing a long-term energy diversification, consequentially they sustained the growth of some relevant industrial areas, involved in uranium processing cycle: mining activities, metallurgy and chemical industry. These aims were oriented to achieve an international prestige. On the other hand, from the beginning, nuclear business was greatly dependent on an intensive state interventation, without ignoring the international cooperation and competition. These features were obviously due to its military origins, the high costs and strategic characters of research and investments (Latouche, 1995; Curli, 2000).

Therefore, in Italy, before the nationalization of energy, occurred in 1962 with the foundation of the National Agency for Electricity (Enel – Ente Nazionale Energia Elettrica), three different groups were involved in defining the nuclear power production line: the National Committee and Agip-Nucleare, a property of Eni Group (Hydrocarbons National Agency), were public, while the last one, directed by Edison, was private. Between 1957 and 1965, their activities led to the installation of the first three atomic power stations, although they were all assembled using English and American technologies.

The reactors exploited three different energy production line, depending on the cooling system chosen:

Edison group bought a Pressurized Water Reactor (PWR), working with enriched uranium, from Westinghouse and built near Trino Vercellese in Piedmont (Northern Italy); Agip-Nucleare contracted a cooperation agreement with the English Nuclear Power Plant Company acquiring a graphite reactor, established in Latium near Latina; while the Committee dealt with General Electric to realize a Boiled Water Reactor (BWR) onshore of Garigliano river near Caserta (Campania, Southern Italy) (Ippolito, 1965; Silvestri, 1968; Maiocchi, 1980; Curli, 2000; Baracca, 2008). These choices were probably driven to some economic and technological reasons; indeed a leading steel factory was still lacking, whereas chemical industry was surely fast-growing (Paoloni, 1992). From a synchronic point of view, during these initial historical phases, technological solutions weren't necessarily guided by the security and, among all, simplicity and economic character.

After 1955, United States oriented the next evolution of the Western nuclear venture. It had been undertaken a sort of Marshall Plan for atomic energy. The United States Atomic Energy Commission, made available information, knowledge, technologies and enriched uranium and, moreover, through several agreements, inspections and controls, led the course of nuclear technology and the political geography of world's reactors. Production lines, adopted by different countries, didn't express carefully scientific evaluations, but they were often influenced by military options and distinct attitudes towards United States (Ippolito, 1960a; Ippolito, 1961; Curli, 2000). For instance, France and Great Britain tried to undertake the path of technological autonomy in this field. On the other hand, the Italian bilateral agreements, especially with American Companies, were an essential tool for reducing costs and unpredictability of results, offering the chance to fill in the technology gap and facilitate a national programme. Only during the energy crisis of the 1970's, nuclear energy was perceived as a real alternative to fossil fuel.

2. THE BEGINNING OF PROSPECTING ACTIVITY IN THE FIELD OF URANIUM MINERALIZATIONS: THE ITALIAN BACKGROUND

Mining explorations were among the earlier activities undertaken in the National Committee for Nuclear Research (CNRN) foundation, mainly since 1961 after changing the name into CNEN. Within the Committee, a special division for mining and geo-mineralogical researches was already created in 1954 (CNRN, 1958-1960).

The different explorations, starting from the 1950's, were focused on Permo-Triassic and Carboniferous formations of Western Alps (Maritmes and Cozie), Tyrrhenian coastal sands, Quaternary lavas of Northern Latium (Viterbo) as well as Central Italy, Calabria fluvial "placers" (CNRN, 1958-1960; Ippolito, 1965; Locardi and Sircana, 1967) and Sardinia. Particularly, a regional scale mineralogical and geochemical prospecting reconnaissance for uranium in several Alpine regions was performed. Along the Italian side of the Alps, the geological surveys especially concerned the metamorphic basement and gradually allowed the localization of some interesting areas of sampling and excavation (Ravagnani, 1974).

Among localized and detailed prospections, it should be remembered those undertaken on Orobic Alps in Lombardy (Northern Italy), where some significant uranium deposits were pointed out, especially those in the upper Valley of Belviso (Sondrio) and Vedello Valley, on the left side of Valtellina (Sondrio, Lombardy). The main uranium ore found was Pitchblende. The mineralizations discovered in that area were very interesting: their genesis wasn't related with Hercynian volcanic activity of late Palaeozoic, as some previous studies believed, but depended on Alpine tectonics. In 1957, radiometric prospections identified in Valganna (Boarezzo), near Varese in Lombardy (Western Lombard Prealps), a significant uranium mineralized zone associated with volcanic formations (tuffs and ignimbrites) of the late Hercynian-magmatism (Ravagnani, 1974). Starting from the same year, the mineralogical explorations regarding different mountain areas near Trento and Bolzano

(Central-Eastern Alps) (CNRN, 1958-1960; Ravagnani, 1974); mining investigations concerned gradually the uranium concretions of Daone Valley as well as Rendena Valley (Trento, Northern Italy) and Venosta (Dall'Aglio, 1966) and Marano Valleys (Bolzano, Northern Italy). The mineralizations, found there, were mostly enclosed in layers of upper Permic sandstones; they occurred almost costantly in formations deposited after post-Hercynian emersion and before the Permo-Triassic marine transgression, showing a sedimentary origin. But the mining districts of greater industrial interest were those of Maritmes and Cozie Alps (Maira Valley, Peveragno, Preit, Bric Colmè, Ambin), with esteemed stocks of about 300 tons of uranium and the most important one of Novazza (Orobic Alps, near Bergamo in Lombardy, Northern Italy), with about 1,000 tons of uranium. In 1965, the proven reserves of uranium ore were about 1,600 tons (CNRN, 1958-1960; Ippolito, 1965; Ravagnani, 1974). However, over the following years, only the exploitation of Novazza's deposit would be revealed economically useful (Ravagnani, 1974). In the first half of the 1960's, the use of Italian nuclear raw materials was considered unprofitable, owing to the excess of uranium worldwide productions (Ippolito, 1965), especially marketed by U.S. and mostly coming from Canada, Africa and Australia deposits.

The surveys, done between 1957 and 1960, were summarized in the first volumes of Studies and researches of Mining Division [*Studi e ricerche della Divisione Geomineraria*]. According to the Committee's five-year plan, the prospecting works should have finished before 1965 (Ippolito, 1965). The results of those examination on field work and geochemical analysis allowed to map the uranium deposits in the Italian Peninsula, but at the same time they clarified the depositional processes of different uranium mineralizations. Prospections were essentially geochemical and radiometric with Geiger counter on field or, seldom, using scintillometers. Explorations covered a total area of about 40,000 square chilometers, including Calabria, Sardinia and volcanic districts of Central Italy (Ippolito, 1965).

Geomineralogical studies represented undoubtedly an effort to manage an energy policy not entirely dependent on the international context and raw materials imports. In fact, between 1965 and 1966, in order to increase uranium researches, CNEN decided to establish a "Mining Activities Group", placed in Clusone near Bergamo (Lombardy, Northern Italy). Collecting various activities previously begun within CNRN, it was founded with the main task to check the earth's surface radioactive anomalies and to realize the map of Italian mineral nuclear resources (uranium and thorium) (Paoloni, 1992). During this period, mining excavations and samples were also led by private companies, such as SOMIREN (Società Mineraria Ricerche Energia Nucleare – Mining Society Nuclear Energy Researches), belonging to Agip-Nucleare, and Montecatini Group, often in partnership with the Committee (Ippolito, 1965).

3. CONCLUSIONS

In almost two decades from 1946 to 1963, a new scientific field, focused on uranium geology, cropped up quickly in Italy. By the way, several laboratories were set up by private companies and government research institutions and agencies for investigating atomic fuels, involving also academic structures and university departments, such as the Chemistry Institute at the University of Rome, the University of Pisa and the Physics laboratories of the State University of Milan with the Polytechnic School of the same city (Silvestri, 1968; Paoloni, 1992; Curli, 2000). The interest towards nuclear energy led also to open a university teaching in "Geology of Uranium" at the Polytechnic School of Milan, held by Felice Ippolito from 1949 to 1959, and to establish a discipline with its own handbooks (Ippolito, 1960b), Italian scientific reviews such as "Energia Nucleare" and "Notiziario del CNEN" and popular publications (Zuffardi, 1957).

Nevertheless, after energy nationalization between 1962 and 1963, Ippolito was put on trial for administrative irregularities in the Committee management (1963) (Curli, 2000), whose activities decreased. So that the Italian nuclear industry weakened until the stagnation of the 1970's as the studies of Silvestri (1968) and Maiocchi (1980) have already demonstrated.

REFERENCES

Baracca, A. 2008. *L'Italia torna al nucleare? I costi, i rischi, le bugie.* Jaca Book, Milano, 206 pp.

CNRN 1958-1960. *Studi e ricerche della Divisione Geomineraria.* Tipografia Pio X, Roma. CNRN report, 3 vols.

Curli, B. 2000. *Il progetto nucleare Italiano (1952-1964). Conversazioni con Felice Ippolito.* Rubbettino, Catanzaro, 295 pp.

Dall'Aglio, M. 1966. Prospezione geochimica per la ricerca di uranio nella Val Venosta (Bolzano). *Notiziario del C.N.E.N.*, 12 (6), 41-53.

De Vivo, B. and Ippolito, F. 1984. *Mineralizzazioni metallifere italiane ed elementi di prospezione.* Liguori, Napoli, 162 pp.

Goldschmidt, B. 1962. *L'aventure atomique. Ses aspects politiques et techniques.* Fayard, Paris, 291 pp.

Hassan, J.A. and Duncan, A. 1994. Integrating Energy: the Problems of Developing an Energy Policy in the European Communities, 1945-1980. *The Journal of European Economic History*, 23 (1), 159-176.

Hewlett, R.G. and Anderson, O. E. 1962. *The New World, 1939-1946.* The Pennsylvania State University Press, University Park, 766 pp.

Hewlett, R.G. and Duncan, F. 1969. *Atomic Shield: A History of the United States Atomic Energy Commission: Volume II 1947-1952.* The Pennsylvania State University Press, University Park, 718 pp.

Hewlett, R.G. and Holl J.M. 1989. *Atoms for Peace and War, 1953-1961: Eisenhower and the Atomic Energy Commission.* University of California Press, Berkeley, 696 pp.

Hobsbawm, E.J., 1997. Il secolo breve 1914/1991. Bur, Milano, p. 712.

Ippolito, F. 1960a. *L'Italia e l'energia nucleare. Cronache di cinque anni.* Neri Pozza, Venezia, 336 pp.

Ippolito, F. 1960b. *Lezioni di geologia dell'uranio.* Artigianato Grafico, Milano, 126 pp.

Ippolito, F. 1961. *Fabbisogno energetico ed energia nucleare.* Cappelli, Rocca San Casciano, 127 pp.

Ippolito, F. 1965. *La politica del CNEN (1960-1963). L'energia nucleare in Italia.* Il Saggiatore, Milano, 294 pp.

Latouche, S. 1995. *La Megamacchina. Ragione tecnoscientifica, ragione economica e mito del progresso. Saggi in memoria di Jacques Ellul.* Bollati Boringhieri, Torino, 215 pp.

Locardi, E. and Sircana, S. 1967. Distribuzione dell'uranio e del torio nelle vulcaniti quaternarie alcaline del Lazio settentrionale. *Rendiconti della Società Mineralogica Italiana*, 23, 163-224.

Maiocchi, R. 1980. Il ruolo delle scienze nello sviluppo industriale italiano. In: Micheli, G. (ed.), *Storia d'Italia, Annali 3, Scienza e tecnica nella cultura e nella società dal Rinascimento ad oggi. Einuadi, Torino, 863-999. Paoloni, G. 1992. Energia, ambiente, innovazione: dal Cnrn all'Enea.* Laterza. Roma-Bari, 455 pp.

Ravagnani, D. 1974. *I giacimenti uraniferi italiani e i loro minerali.* Gruppo Mineralogico Lombardo, Milano, 188 pp.

Silvestri, M. 1968. *Il costo della menzogna. Italia nucleare 1945-1968.* Einuadi, Torino, 408 pp.

Steinert, H. 1959. *Le febbre dell'Uranio. Alla ricerca di metalli nuovi nell'èra dell'atomica.* Garzanti, Milano, 336 pp.

Zaninelli, S. 1996. *Ricerca, innovazione, impresa: storia del CISE: 1946-1996.* Laterza, Roma-Bari, 268 pp..

Zuffardi, P. 1957. *L'uranio. Che cos'è - Dov'è - Come lo si cerca. Guida elementare alla prospezione delle sostanze radioattive naturali.* Hoepli, Milano, 218, pp.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

THE LITHOLOGICAL DISCUSSION IN THE USSR

Gennadiy F. Trifonov

Chuvash State University named after I. N. Uljanov, 428015, Moskovskiy prospect, 15, Cheboksary, Russia.
gen-trifonov@yandex.ru

Abstract. The article is dedicated to the analysis of the Lithological Discussion in the USSR (1950-1952). It shows that in the course of the Discussion a wide range of lithological issues were under consideration. But the essence of the main contradictions in the course of the Discussion was confined to the question of which method (actualism or the comparative lithological method) was to be designated as a principle theoretical method in Lithology. The analysis of the Discussion data can form the basis for the following conclusions: 1) Strong opposition to actualism and the comparative lithological method is incorrect since the first one is a constituent part of the second. 2) Complete rejection of uniformism is also incorrect. Although the nature of geological processes is subject to change in the course of time, yet there exist phenomena that are not liable to conceptual alteration. Moreover, if there was no such kind of uniformity in nature, then no general conclusions would have been possible and hence no scientific laws would have been possible to be laid down. 3) The article justifies the idea of a strong interrelation between the principles and the methods of geological cognition. Method is a principle (i.e. a previously gained knowledge) used for the further cognition. 4) Many of the matters that were questioned in the course of the Lithological Discussion have not been solved yet. The Lithological Discussion nevertheless has played an important role in the further development of the Soviet Lithology, encouraging the methodological thought in Geology. 5) The Lithological Discussion data await for further research. They represent a priceless treasure for geological historians.

1. INTRODUCCTION

One of the laws of scientific knowledge development and hence an essential form of its existence is the conflict of opinions in form of discussions, polemics or disputes. Therefore, the history of any science may not be traced without taking into consideration the conflict of opinions. The history of Geology is no exception either.

The Lithological Discussion in the USSR (1950-1952) exemplifies a workshop that exercised substantial influence on the further development of Geology. The discussion took place during the preparation of the All-Union Conference on Sedimentary Rocks and it was aimed at a wide-ranging discussion on the current state and goals of the science dealing with sedimentary rocks.

The Lithological Discussion has revealed many problems of the then-Geology, in particular, the elaboration level of the methodological issues in Geology, and the psychological atmosphere that had prevailed in the science at that time. It was the time of an ideologized science, bisected into "friends" and "foes" or even "public enemies". One could get rid of a scientist by labeling him as unwanted - often merely on the grounds of someone's personal motives. Communist conferences and geological organization meetings were the enviromets where the attempts to proclaim one of the active participants of the Discussion — Strakhov — a "public enemy" were made. He was saved by a letter signed by a group of the country's respected geologists to the Central Committee of the Communist Party of the USSR initiated by Yablokov. By the way, it was Yablokov who had collected all the Discussion related materials and had managed to preserve and keep them from further research. Those data comprising 16 voluminous folders are filed in the Russian Academy of Sciences Archive.

Strakhov and Poustovalov were the pivotal figures of the Discussion. By the beginning of the event they both had already become reputable geologists. Poustovalov had already reached the apex of his scientific career by the end of the 1930s after publishing his famous «Petrography of sedimentary rocks». Strakhov's major works (dated 1948 and others) were published only after 1945. I would assume that it could have been in a way that caused Poustovalov certain psychological discomfort and he had decided to stop this Strakhov's breakthrough by all means. And it was Poustovalov who had initiated the Discussion.

The main issue of the Discussion was the problem of correlations between actualism and the comparative lithological method against the examination of the wide range of other lithological issues. These are the issues concerning sedimentary differentiation, periodicity of the sedimentary rock forming, sedimentary rock forming evolution alongside with the methodological problems in the science.

Considering all the issues under the debate had brought about very delicate terminological inquiries. For the Discussion participants that had to remain within the basic principles of Marxist-Leninist philosophy, the contradictions between the Discussion participants' views were mainly minor ones. Therefore, it was quite a challenge to see the difference between the diverse views, moreover, they lacked of a rule to make precise conceptual definitions. This was the indication of the science's immaturity in the methodological issues. There was no unique understanding of the essence and the limits of certain implementation methods, in the correlation of principles and methods in the theory of cognition.

2. THE CORRELATION OF THE PRINCIPLES AND METHODS IN SCIENTIFIC COGNITION

Many participants of the Discussion have not presented a clear borderline between the notions "principle" and "method" for the science cognition. In the meantime it is very important for the understanding of many aspects of the Discussion. Therefore I beleive it is necessary a more exact definition of these notions and their correlation. Method is the general way of achieving an adequate and overall reflection of the research subject, alongside with revealing its identity and cognizing its laws. Method is based on a principle - i.e. it is a scope of currently existing ideas on the essence of the research subject. In other words, method represents a principle or a theory aimed at further cognition of the world.

Dialectical method of cognition is considered to be a most general method of cognition. In science dealing with the historical development of material systems, and in Geology foremost, a general scientific dialectical method is concretized in the comparative historical method. Since Geology in particular is a multi-branched science, the comparative historical method in it is concretized and presented in a number of more particular methods within each of the different science branches. Thus, the method of Lithology dealing with the sedimentary cover of the Earth crust is the comparative lithological method. Such a method was first defined by Strakhov (1951) as follows: "The way of solving genetic questions by means of organically bound data on contemporary sedimentation with the data on ancient rocks along with understanding the similarities and differences between the contemporary and the ancient ones is to be called the comparative lithological method in Lithology".

3. COMPARATIVE LITHOLOGICAL METHOD AND ACTUALISM

I believe the comparative lithological method is the main and most general way of studying the evolution of sedimentary rock forming in the Earth history. But all other methods, including actualism, are the means for cognition of peripheral issues and, therefore, they are a constituent part of the comparative lithological method. This very understanding of the correlation between actualism and the comparative historical method (i.e. the comparative lithological method as applied in Lithology) was presented by a number of the Discussion participants (Shatsky et al., 1951; Shantser, 1951; E.V. Shantser et al., 1951, and others).

The nature of these disagreements was confined to the problem of which method was to be designated as a principle theoretical method in Lithology - i.e. actualism or the comparative lithological method. It can be noticed now that such an opposition proves to be a false one since actualism is a part of or a branch of the comparative lithological method. The correlation of these methods is closely related to the discussed matter on the importance of contemporary sedimentary rock forming research for the establishment of a general theory in sedimentary process.

4. CONTEMPORARY GEOLOGICAL PROCESSES AND THEIR ROLE IN THE COGNITION OF THE PAST

The relevance of the contemporary research processes and contemporary sediments researches appears to be obvious. On the one hand, the contemporary state represents a kind of an evolved past state, and on the other hand these facts supply scientists with an opportunity to see and recognize those traits that used to appear in the past merely in the form of hints and allusions — i.e. they were not presented fully but only partially. On the other hand, the contemporary state has at all times been interconnected with the past. Alongside with acquiring new trait, it has been essentially preserving all the phenomena and the processes what, in one way or another, has preserved the features inherited from the past. Marx noted as far back as in 1857: "Human anatomy contains a key to the anatomy of the ape. The intimations of a higher development among the subordinate animal species, however, can be understood only after a higher development as already known (Marks, 1958)".

A hostile opposition to both actualism and the comparative lithological method which is based on the comprehension of the importance of the contemporary state research for the past sedimentary process reconstruction and the creation of a theory for this process was expressed by Poustovalov (1950). Considering Geology and Lithology as the sciences that primarily deal with rocks rather than sediments, he used to criticize the comparative lithological trend as the one that is based on the theory of the sedimentary processes on contemporary sediments research. Thus, according to Poustovalov, the knowledge gained from the contemporary sediments research is useless in unraveling the genesis of ancient rocks because, in this case, "essentially disparate formations" are being compared. In this manner, sediments that have not undergone the diagenesis phase yet are being compared with fossil rocks that have been altered by both diagenesis and epigenesis processes. However, it should be noticed that until 1950 Poustovalov had nevertheless been turning to the contemporary state, trying to reason and convince of the credibility of his points of view (e.g., on chemical and mechanical differentiations). Hence, he writes, "more detailed our knowledge on the contemporary deposits is – more accurately and confidently will we be able to reconstruct the conditions of sedimentary rocks forming" (Poustovalov, 1940). This implies that Poustovalov is basically using the very actualistic method.

Nowadays the relevance of the contemporary state research is generally recognized beyond any reasonable doubt. Still it would be wrong to overestimate the significance of the contemporary research processes. Therefore, Strakhov's criticism is quite reasonable within this context.

So, both actualism and the comparative lithological method were criticized without offering any other possible method. One can not take seriously Poustovalov's suggestion that the comparative lithological method should be substituted by the "historical lithological method". Both are obviously the same.

5. THE PROBLEM OF UNIFORMISM AND ACTUALISM IN THE PROCESS OF DISCUSSION

The majority of researchers that are for actualism believe it implies uniformism and, therefore, they reject it. It is obvious that the problem relies on the very concepts of "uniformism" and "actualism" and they should be specified.

Uniformism is a doctrine of uniformity and continuity in the geological history of the Earth. Should uniformism be rejected? According to many of the Discussion participants: it should be done! (See: Shantser, 1951). But they ignored the fact that there are some other processes in the history of the Earth that are not naturally liable to alteration. Besides, if there was no kind of uniformity in nature, then no general conclusions would have been possible to be made. Consequently, we should be concerned on the right of understanding its place in the complex process of development instead of subjecting the rejection of uniformism to discussion. The development principle being superior to uniformism comprises the latter as a constituent part.

Actualism is a perception of the contemporary research processes as a means for the reconstruction of the past nature processes. Actualism is both a principle and a method that infers conclusions from the contemporary research processes. Actualism is based on the uniformism principle — i.e. on the concept of uniformity. It is disputable whether this actualism deserves existing or not. The answer is positive, since, as it has been noted before, such processes that do not alter their nature in the course of time exist. At the same time it should not be made absolute; moreover, uniformism and actualism are based on this principle and it should not be acknowledged as the main theoretical base for Lithology.

Actualism can also be based on a directional trend principle and on the irreversibility of geological processes. Such kind of actualism is at a higher theoretical level; reasonability of its utilization for the purposes of scientific cognition is beyond any doubt. The comparative lithological method differs from actualism in the way that not only contemporary sediments (and processes) are being compared, but also different age rocks are done so.

Consequently, neither uniformism nor actualism or the comparative lithological method should be rejected, provided the potential resources of the different methods once they are properly implemeted. Those methods and principles are the sides of a more general principle of development. Misapprehension of this fact, the overestimation of one of the methods and the underestimation of other ones and their corresponding principles has provided a gnoseological cause for the Discussion. The cognition method claims to fully cover such a complex phenomenon as sedimentary rock forming evolution. These methods have to be rather extensive and have to be comprised of more than specific methods as to their constituent parts allow us to cognize in detail the specific sides of development. Therefore, when studying such a complex object, the researcher is not able to fully grasp and cover the phenomenon, but he gradually approaches to the understanding of its essence through cognition of its particular sides. This idea has been proved by the full course of Geology development along with the development of its theoretical methods. The mentioned development of the methods is the following: 1. actualism is based on the principle of uniformism and, hence, is reasonably called "the uniformism method" as done by some other scientists; 2. actualism is gradually discharging the uniformism principle and acknowledging the irreversible nature of geological processes; 3. the comparative historical method (the comparative lithological method in Lithology) is true to exist.

During the Discussion it was almost unanimously noted that "the actualism principle (better said the uniformism principle – Gennadiy Trifonov-G.T.) can not be applied as the main methodological base in Geology" (Shantser, 1951). Yet not a single Discussion participant completely rejected actualism. In some of the debated articles (Shantser, 1951; Shatsky et al., 1951), it was pointed out that the actualism principle (*read: – the uniformism principle* – G. T.) as a methodological base in Geology should be strongly rejected. However, it should remain as a means for the past cognition and as the one confined within a certain scope of implementation.

Many Discussion participants (Bushinsky, 1951; Gekker and Osipova, 1951; Shantser, 1951) have considered the comparative lithological method to be as a valid one. At the same time they pointed out that Strakhov's overestimation of the contemporary part implies proclaiming the contemporary sediments research as a principal methodological base in Lithology.

Reasonability of actualism and the comparative lithological method was also highlighted in the summarizing Conclusion of the Conference (The Conference Conclusion). It states, "The Conference considers "actualism" as it was described by Lyell (meaning uniformism) and it is based on a mehtaphysical perception of the geological continuity processes in the Earth history — the Soviet geological science does not agree with this statement. Regardless of the progressive rolepart, this conception has played its role in the fight against the concepts of catastrophism and it still strongly contradicts the scientific data (*though it is hard to agree to that* – G.T.). Practical experience and the laws of dialectical materialism do exist (*actually exist*– G.T.) and should not be rejected (*completely though it has a right to be rejected, rather than appointed to take place* – G.T.). All kinds of holdovers remain and their indirect influence on this conception that comes from the work of the Soviet scientists is intolerable in any form they might appear.

The method of comparing present with past being a common operational method on the naturalistic sciences used to be frequently defined as the actualism method in the works of the Russian geologists. This method should be preserved as one of the most important means of a historical geological research. An obligatory requirement for this method implementation, as well as for other methods in Lithology, is taking into account the development of sedimentary rock forming in the Earth history.

The Conference members consider that the way of solving genetic problems by means of a relative comparison of one rock with another and of ancient rocks with contemporary sediments —which was called the comparative lithological method by the Soviet science— is a reasonable one and, in certain cases, it is a productive method ...".

The Conference conclusion in general seems to be rather controversial. For instance, the idea of "continuous geological processes" is proclaimed as unacceptable (*still such processes do exist* – G.T.). It also contradicts the statement that "the actualism method should be preserved" since every notice on reasonability of actualism in any of its forms implies the acknowledgement of the existence of certain invariable continuous phenomena (features) in the course of geological development.

An essential number of the matters in question were dedicated to the sedimentary rock forming evolution in the geological course of time. It was noted at the Conference Conclusion that the acknowledgement of the sedimentary rock forming progressive development, connected with the general course of the Earth development, represents one of the key principles of the science. In a number of reports the sedimentary rock forming evolution was exemplified by specific cases (Vinogradov et al., 1952; Rukhin, 1952; Bushinsky, 1952 and others). Still it was noted that though the existence of sedimentary rock forming irreversibility was perfectly obvious, its particular occurrences have nevertheless been significantly underexplored as compared to the geological periodicity phenomena.

6. CONCLUSIONS

The analysis of the Discussion data can form the basis for the following conclusions:

1. Strong opposition to actualism and the comparative lithological method is incorrect since the first one is a constituent part of the second;

2. Complete rejection of uniformism is also incorrect. Although the nature of geological processes is subject to change in the course of time, yet there exist phenomena that are not liable to conceptual alteration. Moreover, if there was no such kind of uniformity in nature then no general conclusions would have been possible and hence no scientific laws would have been possible to be laid down;
3. The article justifies the idea of a strong interrelation between the principles and the methods of geological cognition. Method is a principle (i.e. a previously gained knowledge) used for the further cognition;
4. Many of the matters that were questioned in the course of the Lithological Discussion have not been solved yet. The Lithological Discussion nevertheless has played an important role in the further development of the Soviet Lithology, encouraging the methodological thought in Geology;
5. The Lithological Discussion data await for further research. They represent a priceless treasure for geological historians.

REFERENCES

Bushinsky, G.I. 1951. On Trends in Lithology (Moscow). *Izvestia, Academy of Science, USSR, Series Geology*, 3, 61-74. (In Russian).

Conclusions of the Conference on Sedimentary Rocks, 1955. *The Conference on Sedimentary Rocks Issue 2 Reports*, Moscow, 155-170. (In Russian).

Gekker, R.F. and Osipova, A.I. 1951. On the Question of the State and Development of the Soviet Lithology (Moscow). *Izvestia, Academy of Science, USSR, Series Geology*, 3, 40-60. (In Russian).

Marx, K. 1958. From the Economic Manuscripts of 1857-1858. In: Marx, K. and Engels, F. (eds.), *Collected Works*, 12 (2), 709-738. (In Russian).

Poustovalov, L.V., 1940. *Petrography of Sedimentary Rocks*, Parts 1, 2. Moscow. (In Russian).

Poustovalov, L.V. 1950. On the Situation in Sedimentary Rock Science (Moscow). *Izvestia, Academy of Science, USSR. Series Geology*, 4, 68-102. (In Russian).

Poustovalov, L.V. 1951. On the Predominant Initial Principles upon Studying Sedimentary Rocks and Related Natural Recourses (Moscow). *Izvestia, Academy of Science, USSR. Series Geology*, 3, 143-150. (In Russian).

Rukhin, L.B. 1952. Tectonic Types of Sedimentary Rocks. *The Conference on Sedimentary Rocks. Issue 1 Reports*, Moscow, 89-103. (In Russian).

Strakhov, N.M. 1948. *The Basics of Historical Geology*. Government Printing Office, Moscow, 396 pp. (In Russian).

Strakhov, N.M. 1951. On the Ways of Lithological Theory Development. In: Poustovalov, L.V. Yablokov, V.S., Varenzov, M.I., Danchev, V.I., Strakhov, N.M. (eds.), *On the Question of the State of the Sedimentary Rocks Science*, Moscow, 13-19 (In Russian).

Shantser, E.V. 1951. To the Evaluation of the Comparative Lithological Trend in Petrography of Sedimentary Rocks (Moscow). *Izvestia, Academy of Science, USSR. Series Geology*, 3, 21-39. (In Russian).

Shantser, E.V., Yablokov, V.S. and Gordeev, D.I. 1951. On Actualism and the Comparative Lithological and Historical Methods. In: Cherbakov, D.I., Afanasev, G. D., Vlasov K.A., Peive, A.V., Poustovalov, L.V. and Yablokov, V.S. (eds.), *The Data for the Discussion and the Conference on Sedimentary Rocks*, Volume 1, Moscow, 85-95. (In Russian).

Shatsky, N.S., Kosygin, Yu. A., Peyve, A.V., Pushcharovsky, Yu.M., Kheraskov, N.P., Shtreys, N.A. and Yanshin, A.L., 1951. On the Question of Periodicity of Sedimentary Rockforming and the Actualism Method in Geology. In: Poustovalov, L.V. Yablokov, V.S., Varenzov, M.I., Danchev, V.I. and Strakhov, N.M. (eds.), *On the Question of the State of the Sedimentary Rocks Science*, Moscow, 146-163 (In Russian).

Vinogradov, A.P., Ronov, A.B. and Ratynskiy, V.I. 1952. Evolution of the Chemical Composition of Carbonate Rocks. *The Conference on Sedimentary Rocks, Issue 1. Reports*, Moscow, 104-123. (In Russian).

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

LOW TEMPERATURE HYDROTHERMAL METASEDIMENTARY HOSTED URANIUM MINERALISATION IN CARBONACEOUS PELITES OF THE WESTERN IBERIAN PENINSULA

Isabel Arribas[1], Jim Royall[2], David Vals Santos[2] and César Martín Pescador[2]

[1]ETSIMM, Universidad Politécnica de Madrid, Ríos Rosas 21, 28003 Madrid, Spain. isabelkitina.arribas@upm.es
[2]Berkeley Minera España., Cª Madrid 13, 37900 Santa. Marta de Tormes, Salamanca. Spain. jroyall@berkeley.es

Abstract. Uranium was first discovered in Spain in the 1940s and extensive exploration and investigation was carried out dominantly by state run companies until the late nineties. During this period the uraniferous district of Salamanca in Western Spain became the most important area for both exploration and production. The Fe Mine near Ciudad Rodrigo closed in 2000 and was the last uranium mine in Spain to be worked. In recent years exploration activity has increased again through interest from private companies. Activities have included the reassessment of known deposits and also discovery of new ones. The largest accumulations of uranium in the Salamanca region are hosted within Hercynian metasedimentary basement rocks often spatially related to granite contacts. Assessment of existing data and the acquisition of new data confirm that the deposits in the district have a common genetic origin displaying many similarities, however, significant differences also exist between them. The focus has been on the Retortillo deposit but has been extended to cover other nearby uranium mineralizations. The samples studied are slate and/or phyllites, sometimes with andalusite and cordierite caused by contact metamorphism, with marked S1 and S2 occasionally, especially in shear zones. Mineralization shows up filling late fissures with strongly chloritized vein walls. The mineralization consists of quartz, pitchblende, coffinite, iron sulfides and carbonates, quite often as ankerite. Coffinite and pitchblende are generally altered by weathering and converted into gummite and uranium phosphates, mainly autunite, sabugalite and some torbernite.

1. HISTORY

The evolution of the study of uranium deposits in carbonaceous metapelites (black shales) west of Salamanca province, Spain (Fig. 1), especially in the mineralization of the area Retortillo/Santidad-Caridad mine and in the area of Águila are being studied by Minera Río Alagón S.A., representative in Spain of the Australian Company Berkeley Resources, Ltd. (Fig. 2).

In 1953, work began to prospect for uranium in the granite areas of Salamanca and Zamora. At that time, and in accordance with the knowledge that was then in Spain on the mineralization of uranium, prospections were carried out only in granite, leaving aside the Schist Graywacke Complex (CEG) slates of the Central Iberian Zone, when going through these rocks. Therefore, no special attention was devoted to the numerous and large veins and dykes of quartz crossing the granite in the area, in some of which were even made short mining

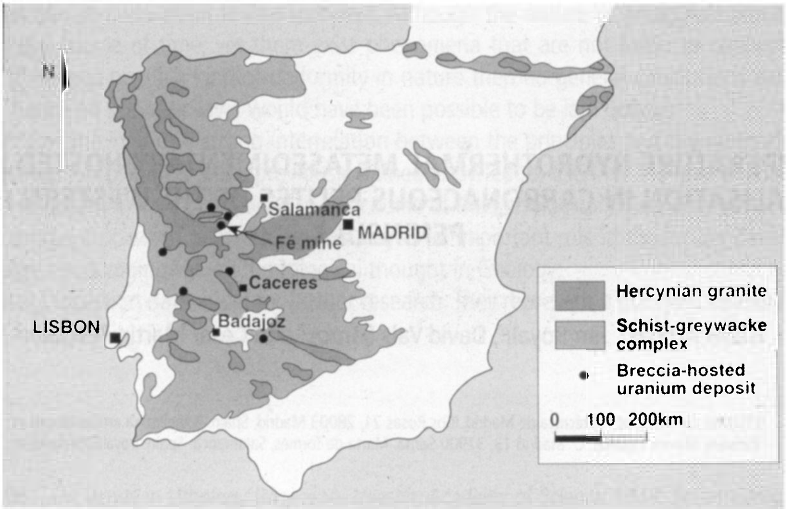


Figure 1. Location of the main mineralized occurrences in the Ciudad Rodrigo area.

operations for recognition. At that time, all attention was focused on the small Valdemascaño mineralization and some small anomalies that would end up being, many years after, the deposits of Casillas de Flores and Villar de Peralonso.

The first uraniferous anomalies in carbonaceous metapelites of the CEG were discovered in 1957, particularly at the contact with granites, when prospecting the carbonaceous metapelites. The first mineralizations were encountered at the zone 26, near Villar de la Yegua, which would later be the uraniferous slate mine Esperanza. Therefore, taking into account these results, also slate areas were included to prospect, and many anomalies were found in a short time, especially the mineralizations of Fé, Esperanza y Caridad.

At present, the largest accumulations of exploitable uranium in the Iberian Península are located in the west of Salamanca Province (200 km west of Madrid) hosted by metasedimentary rocks of the Central Iberian Zone. The Mina Fe was the largest mine, wich closed in 2000. During its operation of over 20 years, 81 Mt of rock were mined and produced nearly 6000 tons of U_3O_8. Since 2004 private companies are re-evaluating Spain's uranium potential in a number of the autonomous regions with positive results.

Figure 2. Exploration drilling in Salamanca province.

In the first phase of exploration on slates still were the same ideas used in prospecting for uraniferous anomalies in granites, i.e., that the uranium mineralization was related with hydrothermal veins whose roots went into the granitic basement, and that the anoma-

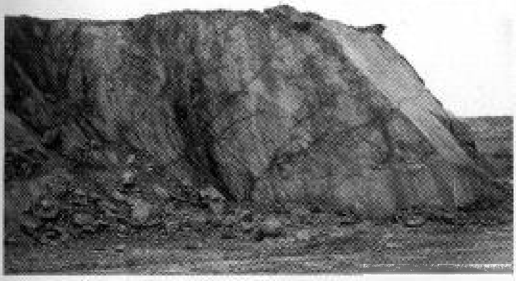


Figure 3. Network of mineralized fractures in the CEG slates.

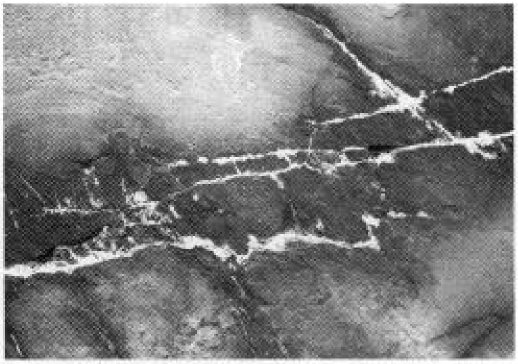


Figure 4. Detail of mineralized joints with pitchblende and coffinite.

lies found corresponded to the top of the veins originated in the underlying granite. Therefore, giving the large surface area of radioactive anomalies and to the dispersion of slate hosted secondary uranium minerals, it was believed that the mineralizations were enriched in depth. This led to exploration work developed according to the same standards that were used in prospecting for veins in granites, i.e., pits, inclined drilling and small mine workings. So, from the beginning, it was found that uranium mineralization in slates, due to the abundance and richness of the occurrences, consisting in autunite and uranotilo in surface, and pitchblende and coffinite in depth, deserved special attention.

Moreover, and as the first time ever found in the world this type of deposits were in Spain and Portugal, which was later known as the Iberian type, it sparked a great interest both for the JEN geologists as other foreign colleagues. In their discussions, the main theme was to establish the origin of the mineralization in slates, i.e., whether these were syngenetic or epigenetic, and if they came from granite or not. Then it was observed that the pits did not follow well-defined mineralized structures, but forming networks of fractures of different orientation and crossing (Fig. 3 and 4). Also saw that the drillings were usually sterile in depth, as is the case of deposits Esperanza and Caridad (Fig. 5), where level -20 contained abundant mineral, -40 was sterile.

Therefore, during the second phase of prospecting, exploration criteria changed. To do this, given the vastness and seemingly shallow depth of the mineralization in the slates, was established an experimental comprehensive system of surveys by wagon-drill, in the area of Villavieja de Yeltes and continued systematically at the Fe mine area. For this method, a 10 m square mesh side and 25 deep, and a radiometry by C.E.R.E.-tube and GTM-14 was used, taking systematic measures each 50 cm in sterile and 25 in interesting areas. These drills showed that the mineralization in the slates was of 2 types: one type corresponding to tectonized areas rich in breccias (Fig. 6) , and another type where the ore is hosted in a network of anastomosed joints and fractures that allow to exploit the slate as a whole (Figs. 3 and 4).

To verify the results of these drills, small pits of 1.8 m wide and 10 m deep were made. Subsequent mineralogical studies showed that some of the fractures on the surface were occupied by pitchblende and pseudomorphic gummites (Arribas 1985), showing the epigenetic origin of the mineralization. These drillings were sunk up to 50 m depth, although occasionally reached 55 to 100 m depth, which recommended the application of geophysical studies proving years after that the mineralization found was vein type and hydrothermal origin, so that the uranium deposits were considered to be a mobilization of the uranium hosted by the original uraniferous metapelites (black shales) of the CEG.

2. GEOLOGICAL CHARACTERISTICS OF THE DEPOSITS

The deposits are hosted in metasediments of Schist Graywacke Complex of the Central Iberian Zone, where dominant host litologies are fine grained pelites, psamo-pelites and psamites.

The mayority of the deposits are located proximal to megacrystaline granites, and it is assumed the same origin for all the deposits:

- Low Temperature Hydrothermal origin but very little alteration.
- Uranium shows no clear association with other minerals.
- The age of mineralization is Tertiary (57 and 37 my).
- The mineralized systems are up to 10 km long by 0,5 km wide.
- All known deposits outcrop and mineralization extends to depth of 100 m.
- A strong structural control with minor lithological influence.
- Uranium mineralization occurs in open fractures.
- Primary mineralization consist on fine grained (<10 μm) pitchblende with minor coffinite and secondary minerals (autunnite).
- Weathering influences the morphology of the deposits.
- Deposits have grade range that oscillates between 400-700 ppm. U_3O_8.
- Contained metal of content per deposit ranges >5Mlb U_3O_8 < 25 Mlb U_3O_8.
- The deposits have an IAEA classification of Vein Type Sub Type Iberian and have very few international analogies.

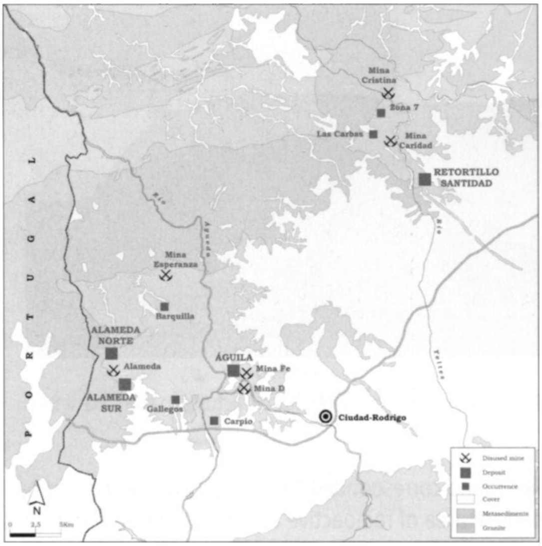


Figure 5. Location of the main uranium mineralized deposits in Ciudad Rodrigo area.

Figure 6. Mineralized tectonic breccia in the FE mine.

3. STUDIED URANIUM DEPOSITS

3.1 Aguila

This area includes Mina Fe, Zona D and M-Sageras from one semi-continuous deposit approximately 4km in strike length (Fig. 7). Águila area is characterised by the lack of nearby granitic material. The deposit is hosted

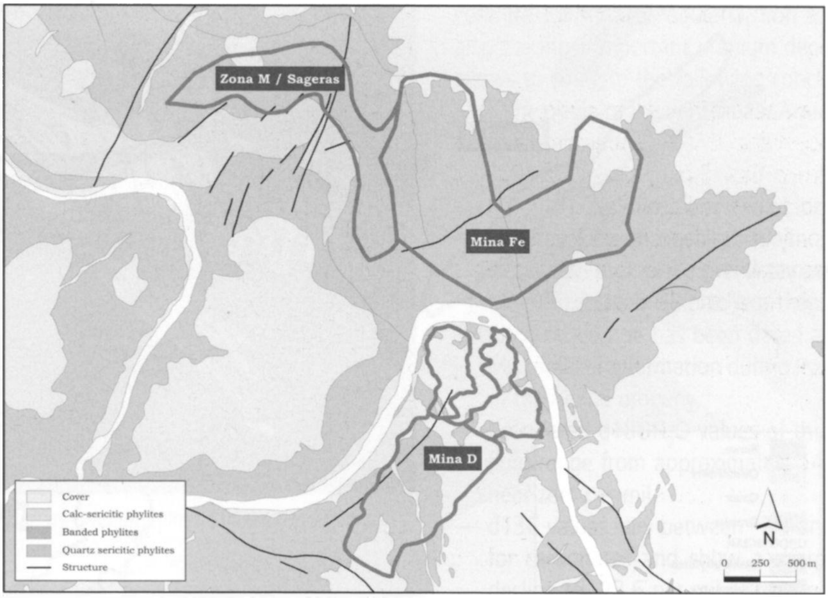


Figure 7. Main uranium deposits in the Águila area.

in the pre-Ordovician metasediments of the CEG, dominantly composed of fine grained pelites of variable composition ranging from siliceous to ampelitic, although within the secuence do also occur locally calcsilicates and amphibolites. Tertiary cover sediments are only preserved on topographic highs or as perched isolated outcrops. The mineralization is fine grained and disposed in veins, breccias and weakness planes.

In terms of metallurgy, primary minerals assemblage is pitchblende and coffinite and present in lesser amounts a diverse secondary mineral assemblage of gummites, oxides, phosphates, silicates and sulphates (Fig. 8)

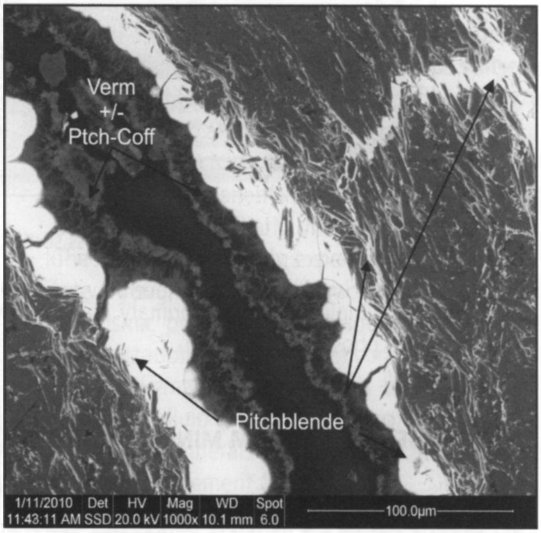


Figure 8. Primary uranium minerals in a veinlet crossing a slate of the Águila area (scanning view).

3.2 Retortillo

This deposit is located very close to Villavieja de Yeltes (fig. 9), in an area 2.5 km long and 0.2 km wide, with an average depth of 24 m. The deposit outcrops in part, in the proximity of the granite contact (Batolito de Bañobarez), and is hosted in Ordovician metapelites with large andalucite crystals crossed by little granitoid dykes.

The deposit is partially covered by recent materials with a preserved deep weathered horizon (Fig. 10).

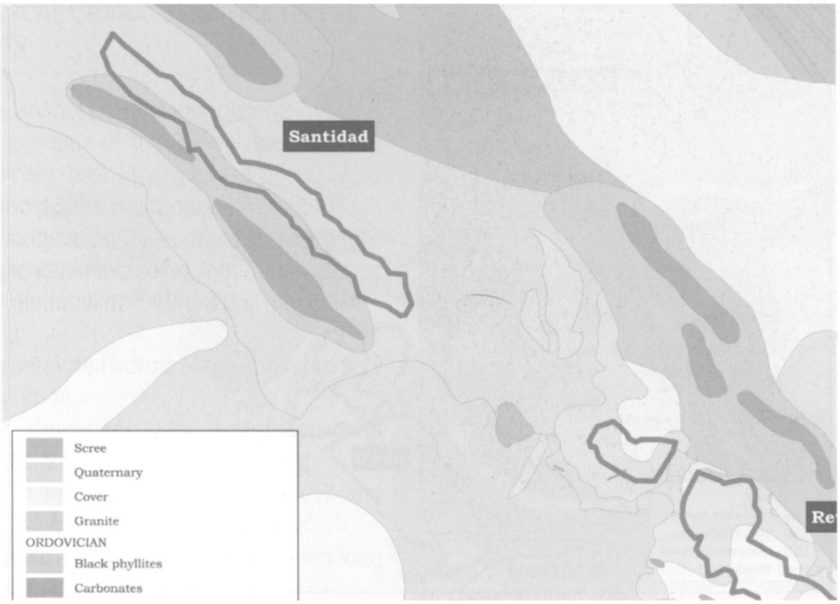


Figure 9. Mineralized deposits in the Retortillo area.

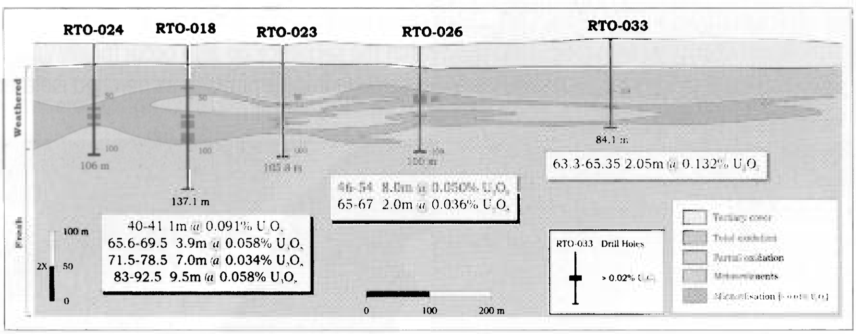


Figure 10. Cross section of the Retortillo area.

In terms of simple metallurgy, primary minerals are pitchblende and coffinite (Fig. 11) with secondary minerals, mainly phosphates (Fig.12)

4. ORIGIN OF THE URANIUM MINERALIZATION

The mineralogical studies (Arribas, 1984, 2007), and the U/Pb geochronological and stable isotope ($\delta^{18}O$, $\delta^{13}C$, $\delta^{34}S$) analysis carried out on micas, carbonates and sulfides from the Fé mine (Both et al., 1994), which is not only the largest uranium deposit of the CEG-hosted type (characterized by the mineral association pitchblende,

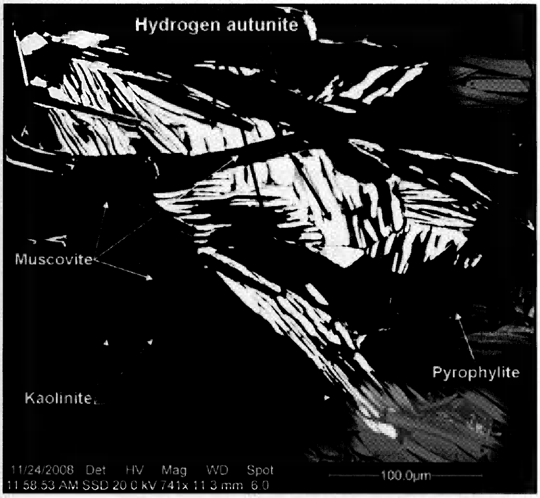


Figure 11. Secondary uranium mineral in the Retortillo deposits (scanning view).

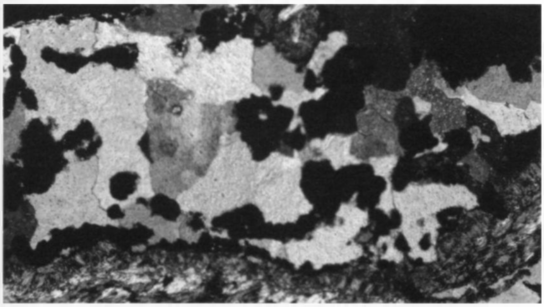


Figure 12. Thin section x10-XPL, from Retortillo area showing the colloidal texture of pitchblende, coffinite and Fe sulphides. The carbonates of the gangue are in the upper part of the figure, and the chloritized vein wall of the muscovite schist in the lower part.

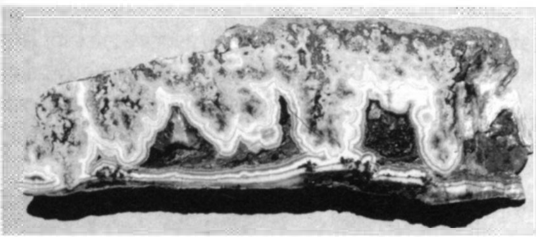


Figure 13. Last deposition of pitchblende filling cavities in layered and stalactitic carbonates.

coffinite, carbonates, adularia, iron sulphides) but also the most important uranium deposit in Spain, allows to come to the following conclusions to explain the origin of the very similar Aguila and Retortillo mineralizations:

— Chlorite compositions and fluid inclusion in carbonates show that wall-rock alteration and ore deposition took place over a temperature range of approximately 280° to less than 60° C.
— Pitchblende age has been dated at 34.8 ± 1.6 My, indicating formation during Pyrenean phase of the Alpine orogeny.
— Calculated d18OH$_2$O values of the ore forming fluid range from approximately 14.5 per mil to near zero per mil.
— d13C values vary between -7.3 and 9.6 per mil for carbonates and show a sharp progressive decline to -23.6 per mil at the end of the final stage of mineralization.
— d34S values of sulphides also decrease from the early stage (around -10 0/00) to later stages (down to -53.3 0/00).

All these data and the combined geologic evidence suggest deposition of the ore from a hydrothermal system that formed in response to the effects of Alpine tectonics on the Variscan basement. Meteoric water descended via steeply dipping faults, and as well as undergoing extensive isotope exchange with, also leached uranium and other components from the metasediments of the CEG, particularly the carbonaceous slates. The fluid was probably expelled toward the surface through a system of fractures and breccias by seismic pumping. The episodic nature of the mineralization may have been controlled by shear fault movements that initiated brecciation and release of fluid pressure, leading to deposition of uranium minerals in joints and cavities of the Hercynian basement (Fig. 13).

REFERENCES

Arribas, A. 1984. Origen, transporte y deposición del uranio en los yacimientos en pizarras de la provincia de Salamanca. *Estudios Geológicos*, 41, 301-321.

Arribas, I. 2007. *Estudio Petrográfico y Mineralógico de Sondeos de la Zona de Retortillo y de la Mina Caridad (Salamanca).* Informe Minera Río Alagón, Salamanca, 13 pp.

Both, R.A., Arribas, A. and Sant-André, B. 1994. The Origin of Breccia-Hosted Deposits in Carbonaceous Metasediments of the Iberian Peninsula: U-Pb Geocronology and Stable Isotope Studies of the Fé Deposit, Salamanca Province, Spain. *Economic Geology*, 89, 584-601.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

HISTORICAL INVESTIGATIONS AT THE NATIONAL SCHOOL OF MINES ON THE CARBONIFEROUS RESOURCES OF THE AMAGÁ FORMATION, DEPARTMENT OF ANTIOQUIA, COLOMBIA

Luis Hernán Sánchez, Andrés Felipe Rodríguez Uribe and Jorge Martín Molina

Facultad de Minas, Universidad Nacional de Colombia, Sede Medellín, Colombia.
lhsanche@unal.edu.co, afrodri1@unal.edu.co, jmmolina@unal.edu.co

Abstract. Two professors of the former National School of Mines (nowadays the National Faculty of Mines) were the forerunners of the geological studies on the carboniferous formation of Amagá: Juan De La Cruz Posada (1913) and Emilio Restrepo (1919). By the year 1913, in the basin known as Hoyo de Amagá no geological map was produced, but the detailed knowledge acquired by Professor Juan De La Cruz on this basin was the basis for the first estimation on coal resources over an area about four square kilometers. The study was focused on supplying the fuel requirements of the locomotives in Amagá and Antioquia. With the partnership of five students, who were developing their tasks in the subject Mining Exploitation and Metallurgy, Juan De La Cruz made the first stratigraphic column of the formation in 1912, identified the syncline disposition of the strata between Amagá and Angelópolis, and classified the coal of Amagá for the first time, indicating it was an economical fuel for stationary boilers, to produce gas lighting, and for the manufacturing of different chemical products. By means of his own studies, Professor Emilio Restrepo correlated in his notes about the carboniferous formation of Antioquia the coal layers of the Amagá's syncline with those coals found in the regions of Urabá, Córdoba, Riosucio-Quinchía, and Cali. His main collaboration is the detailed geological description of the carboniferous formation of Amagá in the Department of Antioquia, before studies and maps on the carboniferous Tertiary of Antioquia were developed (Grosse 1926).

1. INTRODUCTION

The Amagá Formation is located between latitudes 5°40′ and 6°40′ (Fig. 1). Grosse (1926) estimated the thickness of the formation at about 1, 500 m, taking into account the presence of mineable coal seams, and divided it into 3 members. The total thickness of coal can vary between 9 and 14 m, being the majority of the exploitable coal seams present in the middle member of the formation (Member Sabaletas), and their individual thickness varies between 0.6 and 2.60 m. This area is tectonically complex due to the influence of major fault systems such as Romeral and Cauca, which interrupt the lateral continuity of the beds. Figure 2 shows some geomorphological aspects of the area.

2. FIRST STRATIGRAPHIC COLUMN OF THE AMAGÁ FORMATION

Professor Juan De la Cruz Posada, Professor Restrepo, and their students Francisco Acebedo, Juan E. Ángel, Julián Cock, Santiago Londoño, and José M. Mejía, created the first stratigraphic column (Figure 3) registering the carbo-

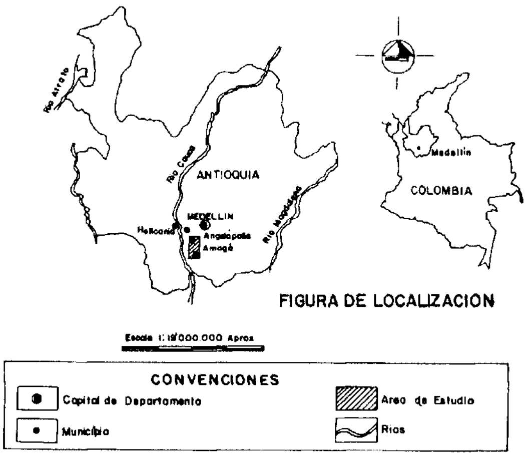


Figure 1. Location area.

Figure 2. Sabaletas Member strata. The pyramid corresponds to a subvolcanic intrusive rock type.

niferous formation of Amagá in 1912, located close to the confluence of La Honda creek into La Clara creek. The total raised width of this column was 70.2 m, indicating the presence of five coal layers of economic importance -they were intercalated with ferruginous sandstones, coal sandstones, refractory sandstones and ferruginous marl.

The Amagá coal was not the adequate one for the rail industry of that date, so they took advantage of its heat of combustion instead, due to high proportions of volatile matters and humidity; explaining that, "those volatile matters escaped from home without making perfect combustion" and the coals are normally "going to decompose with the air; reducing itself to powder, unsteady to produce combustion, to lose the water they contain". Juan De La Cruz also indicates that the coal could present an economic use for vapor and furnace, because one of the advantages of the zone is its high heat power.

After the three analysis performed in his research, De La Cruz the following results on the heat power: 11, 061 BTU, 10, 950 BTU, and 10, 955 BTU per pound. The first two essays were performed at the Laboratory of Westinghouse Machine Company and the third one was performed by the students of the School of Mines of Medellin. Heat combustion of these coals was attributed to the concurrence of low-grade ashes and a high proportion of fixed carbon (see table 1). Juan De La Cruz Posada classifies the Amagá coal as black lignite or bituminous of Campbell.

Assay, without drying	**Seam N°1***	**Seam N°2***	**Seam N°2****
Humidity	11.14%	11.37%	10.45%
Volatile matter	45.15 %	44.41%	43.20%
Fix Carbon	41.92%	43.07%	44.55%
Ashes	1.79%	2.45 %	1.80%
Sulphur	0.33%	0.50 %	—
Heat power (cal/g)	6,145 Cal	6,083 Cal	6,086 Cal

Table 1. Analysis of the coals of Amagá (Posada, 1913).

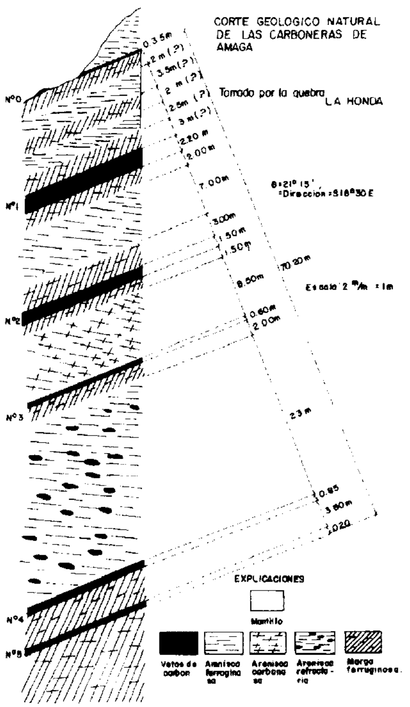


Figure 3. Stratigraphic column made by Juan de la Cruz Posada Restrepo (1912).

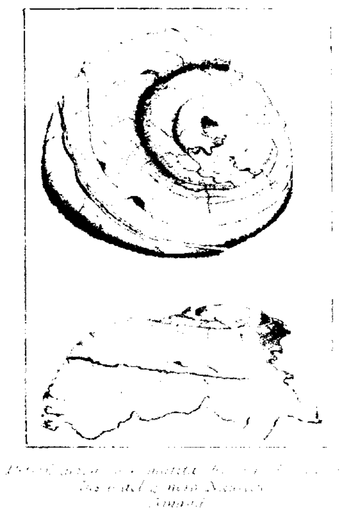


Figure 4. Fossil coming from a clay siderite ball in Amagá.

In addition to the production of the first geological map of the area, Professor Posada (1913) also reported in detail about the geological information of this region. He wrote that the "general direction of the coal layers in the outcrop were the data were taken for the Geological profile creation, is 16° S-30° E, and the dip 21°-15° SW.

Following the dip direction of the seams, the angle of the horizontal layers decreases and then inclines the opposite way, heading NE, forming a synclinal basin -called Batea by the miners-, and then turns into a symmetric one along 3 km approximately. This behavior assured the presence of coal for more than four square kilometers (4 km^2) along the column and schematized the reserves estimation, whose result was of 22, 000 cubic meters, for the five seams in an accumulated width of 5.5 m.

From the paleontological point of view, Posada (1913) said that the carboniferous formation of Amagá is very poor in animal fossils. He reported the finding of one petrified mollusk in a dark hematite, annexing to his report an elaborated draw by hand (Fig. 4): "*I don't have any knowledge about finding a mollusk of this type-Nautilus-in a petrtification in a dark hematite. Vegetal fossils are common*". Professor Posada gave the fossil to E. Grosse (1926), who considered it (without any doubt) from a mudstone siderite of the middle Tertiary Carboniferous of Antioquia.

3. GEOGRAPHY OF THE COAL IN AMAGÁ AND ANTIOQUIA

Professor Emilio Restrepo (1919) published some notes in the annals of the Escuela Nacional de Minas as a contribution to the study on the carboniferous deposits of Colombia.

According to Professor Restrepo (1913), there is a huge carboniferous deposit that occupies some part of the Antioquia subsoil: "*It can be said that it begins at the east of Turbo, heads south and then declines east, along the west of Magangué, traversing the San Jorge River and the Man River. It passes by the west of Cáceres and then it goes south, when it disappears. It appears again in Antioquia, close to Puente de Occidente on Cauca River. Over there, the formation is larger on the towns of Sopetrán, San Jerónimo and then it narrows at Ebéjico. It appears again on the north of Heliconia, Pueblito, and there it bifurcates*".

Figure 5. Professor Juan de la Cruz Posada Restrepo (photograph provided by his family).

3.1 The outcropping coals on the south of Pueblito

About the outcropping coals on the south of Pueblito, the author states: *"One branch of the bifurcation goes from Pueblito and follows the general strike to the south, with a soft deviation to the east. From there, it follows the way to Angelópolis, crossing the Amagá Basin and continues to the Sinifaná creek, going to Fredonia, Combia and Cerrobravo; traversing the Poblanco River and heading to La Pintanda. It goes from Poblanco River to the Jericó Bridge, crossing the Cauca River, and becomes narrower between Támesis and Los Farallones...". "The other branch of the bifurcation goes from Pueblito to the south, declining to the west, going to La Horcona creek, and then heading to Los Micos, Titiribí, Corcobado, Sabaletas, Venecia, and to el Paso de los Pobres at the Cauca River...".*

Professor Restrepo clarifies that *"this huge carboniferous deposit is interrupted by eruptive rocks or by the water action".*

As far as the Historical Geology is concerned, he deduced this coal must be deposited at the end of the Cretaceous or at the beginning of the Tertiary, ages confirmed by studies of palynology.

As it is noticed, these descriptions on the geography of the carboniferous formation of Amagá were well studied by Professor Restrepo (1919) and this indicates it was not possible for Grosse to count with the descriptions when he made the geological map between Arma River and Sajonal (Olaya) (1920-1923). Also, Professor Restrepo (1919) does not include in the bibliography the report from Grosse (1926), although there is a reference to it at page 147, in which the authority is given as a raised profile by Grosse on the middle of inferior member, when it was opened due to a landslide on the north of the Ferrería.

4. RESOURCES AND EXPLOITABLE RESERVES OF THE AMAGÁ COAL

Based in a geological mapping of the Amagá Basin and limited to a polygon between Angelópolis and Amagá (El Pedrero sector) from north to south, and between the Amagá granite and the Pueblito diorite from east to west, in a 10.5 Km^2 surface, Professor Posada draw a profile that has been lost, and that is different to the one from Gross' report, page 47, 1926. For the estimation of resources he used a seam of 1.10 m (seam N° 20), which was decomposed and all the seams had an inferior thicknesses of 0.5 m, finding a coal thickness of 10 m. To define the minable coals he reported: *"As business information, it is possible to say that not all the coal is exploitable, there is small consumption nowadays (beginning of XX century) and, consequently, it reaches a low price on the market, and the exploitation requires expensive assemblies for the inferior layer located below the water levels. Considering this, it is just possible to say that the seam of 2.20 m of thickness is exploitable, some of the 1.30 m seams and in a very small portion of the others. It is possible to guess that from the seven kilometers of surface just 3.5 m of thickness are exploitable. From this, we can conclude that the exploitable coal of the Amagá Basin is (24 ½ m^3, or what is the same, 29, 400, 000 tons.*

In addition to that, we can report about the stability of the exploitation that some coal rests, the ones which are not easy to replace by wood due to the lack in the area, and the calculations of the pillars of coal are equivalent to a 25% of the seam of coal (data taken from practice),thus the exploitable coal is approximately of 22 million of tons".

It is important to clarify that Grosse (1926) reported 8.5 million of tons for this area, but having into account superior thickness of 2 m.

5. ENVIRONMENTAL CONDITIONS OF THE COAL EXPLOITATIONS AT THE BEGINNING OF THE XX CENTURY

Professor Restrepo (1919) finished his paper with a very important statement, still effective today, 100 years later: *"the exploitation process performed to extract this Amagá coal is rudimentary, uneconomical and dangerous for miners. We hope our Government issues some legislation on the way these seams are exploited, in order to protect the worker's lives, as well as to take advantage of the bigger amount of coal, which can be considered as a public wealth".*

REFERENCES

Grosse E. 1926. *El Terciario Carbonífero de Antioquia.* Reimer, Berlín, 329 pp.

Posada R.J. 1913. *Notas sobre la Formación Carbonífera de Amagá.* Anales de la Escuela Nacional de Minas, Medellín, 237 pp.

Restrepo E. 1919. *Apuntes Sobre la Formación Carbonífera de Antioquia.* Anales de la Escuela Nacional de Minas, Medellín, 631 pp.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

HISTORY OF GEOLOGY – A DISTANCE LEARNING EXPERIENCE

Filomena Amador

Universidade Aberta, Rua da Escola Politécnica nº. 147, 1269-001 Lisboa, Portugal. famad@univ-ab.pt

Abstract. The current work explores a teaching experience carried out in an undergraduate degree in Environmental Sciences, which is delivered according to a pedagogical model developed for online education. The subject taught was History of Geology and special attention was given to the educational role of scientific illustrations and its potential in this context.

1. INTRODUCTION

In this paper, we examine the integration of themes of History of Geology in the *curriculum* of an undergraduate *b-learning* degree in Environmental Sciences offered at Universidade Aberta (Portugal). The main purpose of the course is to promote and develop a set of professional skills and competences within Environmental Sciences that include training in the areas of Natural Heritage, Environmental Health, and Environmental Management and Sustainability.

The integration of the History of Geology in one of the *minores* of the course is justified by the fact that it provides a cross-disciplinary view. At the present and in the context of the emergence of Sustainability Sciences, we need to implement approaches that create a bridge between social and natural sciences. So, our goal is to develop in the students a sense of belonging to a community and a space. These elements are the history they need to understand as a condition for an active citizenship, including in the latter the development of attitudes and skills favorable to geo-heritage conservation.

The scientific illustrations can be an excellent teaching resource to achieve this kind of goals. According to Mathewson (2005), there are three closely linked factors that we need to pay attention to when dealing with visual learning in science education: observational skills, levels of visual abstraction, and the use of models. From this perspective, we have designed a set of e-learning activities focused on historical images.

2. CURRICULAR CONTEXT

Universidade Aberta (UAb) is a distance-teaching university that began its activities in 1988. It puts together a student body of approximately 10,000 students. A more modern approach, based in a constructivist pedagogical model, was introduced in 2006. The university teaching model rests on e-learning and intensive use of different online communication tools. Because online learning requires specific skills from the student, all degree programs include a preparation program. The assessment of knowledge and skills, centered on a system of year-long assessment, can assume different forms, as predicted in the teaching model.

UAb, as a public distance-teaching university, embraces as its basic mission to train students whom, whatever the reasons might be, were not able to enter or complete higher education studies at the appropriate time. At the same time, UAb tries to meet the expectations of all those who, having obtained a university qualification, wish to convert or update it. This means that, by vocation, we try to answer the expectations of a life-experienced adult public and for the most part already pursuing a professional career.

The degree in Environmental Sciences is aimed specifically to the following audiences, either within the public or private sectors: central administration staff, regional decentralized services, and local administration; rural and ecotourism managers; managers of small business offering services in the area of the production and commercialization of organic products; public and private companies working in the field of Environmental Sciences; technicians in museums, botanical gardens, zoos, aquariums, nature conservation centers and regional development associations; tourist guides interested in developing ecotourism projects; animators in summer camps, learning farms and youth hostels; members of NGO's and organizations concerned with environment, social intervention and local development.

In general, the purpose of the course is to promote and develop a set of professional skills and competences within the Environmental Sciences. These include Natural Heritage, Environmental Health, and Environmental Management and Sustainability with three optional *minores*, each composed of 60 European Credit Transfer System (ECTS), with 10 curricular units in one academic year. The first two years are composed of mandatory curricular units of Science and Environmental Technology (40 ECTS), Biological Sciences (22 ECTS), Earth Science (22 ECTS), Mathematics (12 ECTS), Chemistry (12 ECTS), Physics (6 ECTS), and (Law) Legal Sciences (6 ECTS); for a total of 20 compulsory curricular units.

This 1st cycle program (three scholar years) has been delivered according to a pedagogical model developed for online education, which is based on four major principles: student-centred learning, flexibility, interaction and digital inclusion. This pedagogical approach makes possible for the teacher to organize and structure learning activities in each curricular unit and for students to know their role and responsibility by having at their disposal: the curricular unit plan, the formative activities plan and also a learning card. Students have to produce two or three e-folios -e-learning activities- for continuous assessment and a *p*-folio performed in a face-to-face setting at the end of the semester. Students can also choose at the beginning of the semester to take a final exam, rather than continuous assessment as described by Pereira et al. (2007). The final grade will result from the combination of the continuous assessment (40%) and of the final exam (60%). It was also established that in order to pass each course it is mandatory to obtain a 50% success rate in both constituents of the final grade—i.e. continuous assessment and final exam.

The course is managed through an open source system (*Moodle*). The first couple of weeks, prior to the beginning of the 1st semester, consist of an introduction to both the course management system and the UAb pedagogic model. The semester is defined as a twenty weeks period, where the last five weeks are aimed to the final assessment. All UAb courses have a common structure organized as follows: the curricular units are composed of virtual classes (each with a specific site), a coordination site for students, a coordination site for the teaching team, and a "virtual café" where students can socialize. The undergraduate program is all online except for two curricular units: Fieldwork I and II. In each of these units students attend to 5 days of face-to-face field work classes, including laboratory and study visits to different regions of Portugal.

3. THE CURRICULAR UNIT OF "HISTORY OF BIOLOGY AND GEOLOGY"

The syllabus of this curricular unit consists of six topics, considered significant from a standpoint of the development of concepts and theories. In each topic we analyse models and theories, as well as personalities and institutions, highlighting the thrill of discovery and the discussions among naturalists and scientists, following the evolution of the interactions established between man and nature in the course of history. It is important to notice that students enrolling this discipline already concluded a number of other curricular units on the domain of Geosciences.

The syllabus of "History of Biology and Geology" is divided into 6 main topics:

— "Observation, experimentation and explanation". This topic includes the following themes: Discovery of New Worlds in the sixteenth century, Cabinets of Curiosities, Cabinets of Natural History, Botanical Gardens and Museums of Natural History; The Scientific Revolution in the seventeenth century; New scales of observation; The role of scientific illustration in the evolution of science.
— "Classification and explanation of the living world". This topic includes: The classifications of Linnaeus; Cell theory: a unification of the living world; The role of scientific illustration in the evolution of science (cont.).
— "The conquest of time in Geology". This topic includes: Theories and histories of the Earth; Problem of the origin of fossils. The geologic time and the succession of fossil floras and faunas; Uniformitarianism *versus* catastrophism; The History of Geology in Portugal.
— "Evolutionary processes in living things". This topic includes: The evolutionism of Lamarck; Darwin and the transformation of species.
— "Volcanic and seismic phenomena". This topic includes: Gaspar Frutuoso -a precursor in the study of volcanism; The Lisbon earthquake of 1755 -explanations; From the Theory of Continental Drift to the Theory of Plate Tectonics.
— "History of environmental conceptions". This topic includes: Historical roots of key environmental concepts; Importance of historical values in the conservation of natural heritage.

Although we could be tempted to follow a chronological order, where the main axis would be division by periods of time, namely centuries, we should also be aware of the possible misunderstandings this approach could lead to:

— Historical divisions are always intellectual constructions, so they can often generate controversy.
— This type of division would require addressing such a diversity of topics, for each period of time, that we would probably transform the program of this curricular unit in a general history one, essentially descriptive, and with little interest in terms of Environmental Sciences.
— On the other hand, the difficulty in reconciling vertical and horizontal views (Kragh, 2001), allowing highlight of historical episodes and turning them into special units of analysis, would be seriously compromised.

Thus, we have decided upon an organization on two levels. First we start by selecting six topics covering essential aspects of the historiography of Biology and Geology, followed by a set of sub-topics that includes a group of reflection themes, supported by examples of scientific iconography.

Teaching materials are available in the Virtual Learning environment of the curricular unit. In each of the topics students have at their disposal a set of texts organized in introducing knowledge (IK), building knowledge (BK) and deeper knowledge (DK). In the first one an example or case study is presented. It is aimed to introduce the topic and allows us reviewing key concepts considered basic to understand the issues that will be addressed and, at the same time, it motivates students to study. Following the order, BK provides the fundamental text that corresponds to the different subtopics listed in the curriculum. This text is based on the "History of Biology and Geology" textbook, although the subjects are presented in a different organization and with distinct levels of development (Amador, 2001). Finally, in DK, suggestions for a deeper knowledge of the subject are offered.

4. SCIENTIFIC ILLUSTRATIONS AS A LEARNING TOOL

At this point, we emphasize the introduction of scientific illustrations as a strong resource. In this curricular unit the scientific iconography is included not only in the program, but also as a methodological tool that allows more appellative and integrating study of the different themes. We must not forget that visual iconography has always been one of the most important supports of scientific communication. History of science shows that, in every period, men's representations and drawings were influenced and constrained by their previous knowledge, and therefore, in order to understand its epistemological functions, further analytical attention to the pictorial sources is necessary (Rudwick, 1992). In a broader perspective it is also necessary to bear in mind that scientific illustrations are products of historical development that involve the intersection between artistic and scientific conventions. These images can only reveal the scientific knowledge of a period, but also are a manifestation of artistic practices and visual conventions accepted at the time they were produced (Rudwick, 1992). They could be an attempt to represent what is observed, establishing eventually an organization or even interpreting the facts by building a model. Sometimes the construction of such representations is a process of successive analog inference, based on fragmentary evidence.

In the period of Portuguese Discoveries the illustrations included in books, letters, catalogs and reports were a privileged tool for transmitting testimonies of a New World. In this manner, they could be seen as evidence of the perplexity of a distinct nature and as a way of knowing how this nature was observed and explained (Lopes, 1998). At the end of the fourteenth century paper printing techniques were already used and enabled the common use of illustration, especially in religious texts. However, it was in the late seventeenth century that the use of the etching technique allowed an increase in the detail of the depictions of natural objects (Rudwick, 1985). The use of new instruments for observation and new techniques of representation, such as the frontal planes or the suppression of the fund in depictions of natural objects also implied substantive progress. Subsequently, the philosophical journeys undertaken in the eighteenth century caused a new stream of data and led to a growing appreciation of visual representations as the preferred way of transmitting knowledge. Later, in the nineteenth century, when naturalists accepted the idea that there was history prior to the appearance of man on the Earth, images began to appear allowing the recreation of imaginary and unknown worlds in a credible way (Amador, 2007).

In this curricular unit scientific illustrations are used as the core of the training and the assessment activities that are developed. We start by selecting a set of images from which we propose a series of questions that could induce reflective processes in students and force them to make connections that otherwise they would not do. In table 1 we present two examples of these activities: one in a training context and another one in a situation of continuous assessment of students.

Scientific illustration	**Problematization**
 *Duria antiquior*: Henry De la Beche's cartoon of life in "a more ancient Dorset" (1830) (Rudwick, 1992, p.45).	Can we ever be sure of representing nature in a trustworthy manner? Can we represent, for example, a particular natural entity, a crystal of calcite, a fossil, a living being, in the totality of its features?
 Painting of the Austrian Joseph Anton Koch (1768-1839), *The Falls Schmadribach*.	The works of Alexander von Humboldt (1769-1859) also influenced many artists in their ways of representing nature. The illustration corresponds to a painting of Joseph Anton Koch Austrian (1768-1839), *The Falls Schmadribach*, is considered an example of this influence. Justify this statement. (This activitie was inspired in Drahos, 2008). "Les Chutes de Schmadribach" in *Pour la Science*, n° 374, p. 106/07).

Table 1. Examples of e-activities proposed to the students.

In the academic year of 2009/2010 we carried out a research work where content analysis of the texts produced by students when answering questions about some of the illustrations took place. We tried to understand what they thought about historical evolution of the values and conceptions related with nature (Amador, 2010). Collected data and information showed that the educational use of iconography may have been a stimulus or factor that led to the development of cognitive skills. An additional conclusion is that there is a need to develop the relation between the historical data and the present environmental ethics. This can be achieved by strengthening the vertical historiographic view. However, results also revealed the need to achieve the establishment of direct linkages between them.

5. CONCLUSIONS

From the view point of educational research it becomes relevant to perform a SWOT analysis on the pedagogical practice, followed by the consequent reflection, where the strength and weak points of the teaching materials and strategies become evident. The conclusions should be the base for the future of this practice.

In general, our experience as lecturers of this curricular unit reveals that there was a deeper understanding of the subjects where scientific illustration was used in relevant contexts, in contrast with other matters. Secondly, we think that in order to provide a better autonomy of students in the future, it is necessary to make available more links to primary sources and a great offer on training exercises, because it induces students to structure and write texts and reports. The e-learning methodologies require students to have a good capacity to express their ideas through writing. This means we need to strengthen the connection between text and image.

REFERENCES

Amador, F. 2007. A função epistemológica das imagens na Geologia histórica – perspectiva evolutiva. *Episteme*, 26.

Amador, F. 2010. Contributos da História da Geologia para a compreensão da evolução das concepções sobre a natureza, num curso de licenciatura em Ciências do Ambiente. *VIII Congresso Nacional de Geologia, Braga, Revista Electrónica de Ciências da Terra*, 15 (2), 1-4.

Amador, F. and Contenças, P. 2001. *História da Biologia e da Geologia*. Universidade Aberta, Lisboa, 235 pp.

Lopes, M.S. 1998. *Coisas maravilhosas e até agora nunca vistas. Para uma iconografia dos Descobrimentos*. Quetzal, Lisboa, 271 pp.

Kragh, H. 2001. *Introdução à Historiografia da Ciência*. Porto Editora, Porto, 240 pp.

Mathewson, J.H. 2005. The visual core of science: definition and applications to education. *International Journal of Science Education*, 27 (5), 529-548.

Pereira, A., Mendes, A.Q., Morgado, L., Amante, L. and Bidarra, J. 2007. *Modelo Pedagógico Virtual da Universidade Aberta*. Universidade Aberta, Lisboa, 112 pp.

Rudwick, M.J.S. 1985. *The Meaning of Fossils*. University of Chicago Press, Chicago, 304 pp.

Rudwick, M.J.S. 1992. *Scenes from Deep Time*. University of Chicago Press, Chicago and London, 294 pp.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

DINOSAUR FOOTPRINTS OF ENCISO AND CORNAGO, AND PYRITES FROM NAVAJÚN (SPAIN)

Félix Pérez-Lorente

Universidad de La Rioja and Fundación Patrimonio Paleontológico de La Rioja. Madre de Dios 51-53, 26006 Logroño, Spain.
felix.perez@unirioja.es

Abstract. The Cameros Basin is a huge depression filled with continental sediments of the Kimmeridgian-Albian age. This basin gathers several geological particularities, and some of them have been selected for this field trip guide -i.e. the dinosaur footprints and the pyrite deposits. In La Rioja region there are approximately 149 sites, putting together a total of 10, 000 catalogued dinosaur footprints. The ichnotaxonomy, behaviour (individual and group), and relations between the physical condition of the soil and the behaviour of the dinosaurs, have been studied in this region. New ichnotaxa have been determined and new guidelines on the behaviour of dinosaur groups and individuals (family groups, swimming dinosaurs...) have been issued. In addition to dinosaur traces, there are also other traces belonging to vertebrates such as crocodiles, tortoises, and birds. Some of these sites have been adapted for tourists, and a Museum and a Paleontological Centre (Igea) have been built in the area. The locations chosen to visit on this field trip are: the Enciso Museum and the sites of Los Cayos, Barranco de Valdecevillo, and La Virgen del Campo. The metamorphism of the Albian age is the origin of the formation of pyrite crystals in Mesozoic sediments (Toarcian-Albian). In some places, these crystals are exceptionally beautiful and big. The crystalline forms can appear as simple forms (cubes, pyritohedron), compound forms (cube + pyritohedron, cube + octahedron), or aggregates and twins. In Mina Victoria (Navajún) - an exploitation still working nowadays - the cubes and their aggregates of pyrite are spectacular.

1. DINOSAUR FOOTPRINTS OF ENCISO AND CORNAGO

1.1 La Virgen del Campo (Enciso)

Located on the south of Enciso (Brancas et al., 1979), this site gives us a lot of information about trackmakers, dinosaur behaviour and environmental conditions thanks to the huge number of ichnites and their big size (Fig. 1) - i.e. more than 600 ichnites have been found here, being the footprints predominant (Casanovas et al., 1985, 1989, 1991). A trackway made out of 20 prints and another of a theropod —which moved at 4 km/h and of which there is a record of a possible final leap— are especially important.

This theropod trackway crosses another ornithopod one, leaving their prints arranged in a chaotic way. The chance of a fight between these two dinosaurs leaving their prints cannot be ruled out (Pérez-Lorente et al., 1986, 2001).

As well as the prints, the following ones are also of interest:

1.- Claw marks in numbers 1 to 3, which finish in a hump of mud. These have been interpreted as a dinosaur swimming whose claws merely scratched the bottom (Ezquerra et al., 2004, 2007).

Figure 1. Dinosaur footprints from La Virgen del Campo (Enciso).

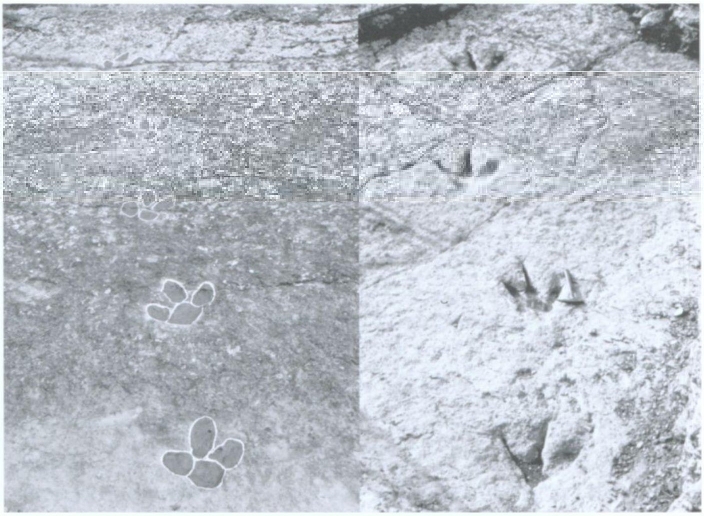


Figure 2. Dinosaur footprints from Barranco de Valdecevillo (Enciso).

2.- Scratched ungeal stries and narrow and white bands superposed to ripples. The ungeal stries are longer and they are associated with the bands. The associated long stries and band are pistes of progression from submerged crocodiles (Ezquerra y Pérez-Lorente, 2003).

3.- An area of rounded marks or undertracks of a higher layer of true footprints.

4.- Parallel grooves in a band about 50 cm width where branches were dragged along the bottom or where trunks were floating (Pérez-Lorente, 2001).

5.- Burrows made by invertebrates (bivalves) which went from hole to hole dragging themselves across the floor during the change (Blanco et al., 1999).

6.- Bioturbartion invertebrate holes.

7.- Fragmentation of the bottom by cracks and fractures, slumps and mud tongues of sinsedimentary origin. There are footprints split on either side of the fractures.

In this site there are footbridges so tourists can have a better look at the ichnites and also to protect the site (Caro y Pavía, 1998), preventing people from walking on the rock.

There are two sculptures from both, a carnivorous and an herbivorous dinosaur, which simulate the attack of the former to the latter. These real-scale figures represent the hypothesis of the struggle abovementioned.

1.2 Barranco de Valdecevillo (Enciso)

This site is a long narrow passage located at the top of a bed that outcrops on the west side of the gully. Theropod, ornithopod and sauropod prints have been recorded here (Casanovas et al., 1989; Viera and Torres, 1979) (Fig. 2).

At the lower part there is a theropod trackway with four footprints made by a biped dinosaur. There are deep, long and very thin toe marks (Valle, 1993) of *varus* gait (the normal gait for bipedal dinosaurs). The narrowness of the trackway and the arrangement of the footsteps indicate the way the dinosaur walked. Hip height was 2.5 m. In the K-phase of the print formation the mud collapses into the shaft.

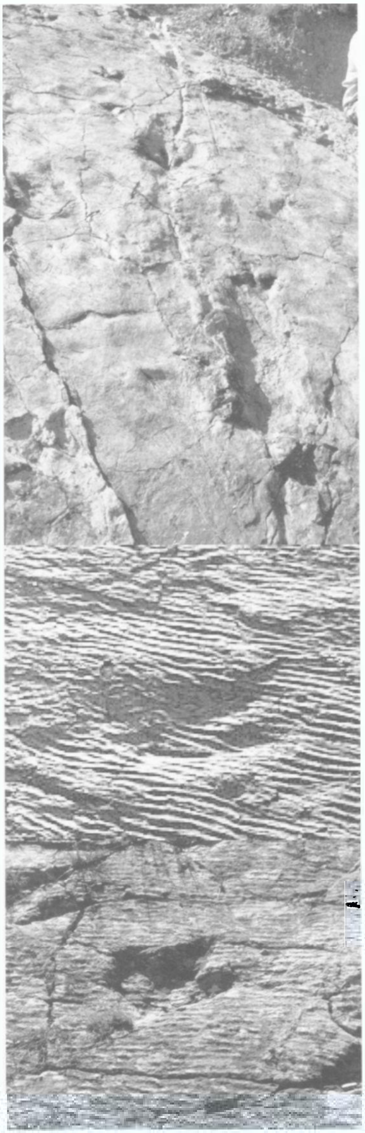


Figure 3. Dinosaur footprints from Los Cayos (Cornago).

There are three ornithopod trackways located near the middle section — tridactyl with four round pads. They are parallel and oriented toward the same direction. The two outermost trackways have big footprints (more than 30 cm long), while the middle one is smaller (22 cm). They have been interpreted as belonging to a family group of two adults with their offspring walking between them (Pérez-Lorente et al., 1986, 2001).

The trail of one adult ornithopod (herbivorous) crosses that of a theropod (carnivorous) with long toes and acuminate tips. The different possibilities are that:

i) the theropod was a piscivorous dinosaur.

ii) the time between the printing of the trackways could have been very long.

Some metres up, there are two parts of the same sauropod trackway. The path of the sauropod trail is straight and normal until the feet and forelegs prints separate — stride shortens and walking speed is reduced, congruent with a sudden and forced change in the trackway direction.

There are 13 more trackways in the upper end of this site.

The first 4 theropod prints are protected by a tiled roof. Along the whole site there is a footbridge for improved viewing and protection of ichnites. In addition, there are reproductions of a family of iguanodons composed by two adults and a baby, and a brachyosaur sized according to the scale of the prints found in the site. There is also a tarbosaur and another iguanodon around the area.

Megalosauripus prints have been identified in Barranco de Valdecevillo (Casanovas and Santafé, 1974).

1.3 Los Cayos (Cornago)

This site contains 700 ichnites of different size, which all together form more than 45 trackways (Fig. 3). The site consists of some outcrops at different stratigraphical levels: Los Cayos S and D in the lower part, Los Cayos A, B y C in the middle part, and Los Cayos E in the upper part (Moratalla et al., 1989, 2003). The footprints belong mostly to theropods, but there are also traces of ornithopods, sauropods (Moratalla and Hernán, 2008), pterosaurs, birds and turtles (Moratalla and Sanz, 1992; Sanz et al., 1985). Dinosaurs ichnites are bigger than the other ones. Another remarkable fact is the presence of two theropod trackways containing tail drag marks.

Many of the theropod prints are undertracks in a rippled study surface (s-surface) of exceptional beauty. Some of these footprints can reach 10 cm deep.

Theropod and ornithopod footprints are tridactyl, although there are some theropod ichnites with four toes marks (the first toe or hallux).

The predominant direction of the tracks is from east to west (86 % are west oriented, and the rest of them are east oriented). This bi-directional pattern has been linked to the geographical conditions which forced the animals to pass through this zone.

The best conserved area of the site is protected by a canopy in order to prevent weathering and animal deterioration. There are a number of explanatory panels which offer information regarding scientific content.

Bueckeburgichus and *Therangospodus* have been identified in Los Cayos (Moratalla, 1993).

1.4 Enciso Palaeontological Museum

This is an essential stop for the footprints sites' visitors. Information about scientific contents, publications, location of sites and touristic regional points of interest is displayed in the Museum.

The Museum is divided in three floors. The lower floor includes a conference room and a dinosaur play hall for children. The middle floor includes a permanent exhibition on dinosaur history, footprints formation and excavation, planning and study of the palaeoichnological sites. It counts with panels, TV-monitors, scale models, footprint specimens, teeth and bone reproductions, etc. The upper floor is where the administrative bureau of the "Patrimonio Paleontológico de La Rioja" Foundation, the library and meeting and working rooms, in which researchers can consult bibliographical resources, are located.

The principal Museum research topics are:

— Study of La Rioja dinosaur footprints;
— Implementation of restoration methods for the conservation and protection of the rocks from the ichnological sites;
— Work related with consultation about La Rioja palaeoichnological sites.

2. NAVAJÚN PYRITES

There are pyrites of neoformation in several localities of La Rioja which, in some cases, provide very showy specimens (Fig. 4). Pyrites are found in sediments of mostly Lower Cretaceous Cameros's Basin (Alonso-Azcárate et al., 2002; Mata and López-Aguayo, 2002).

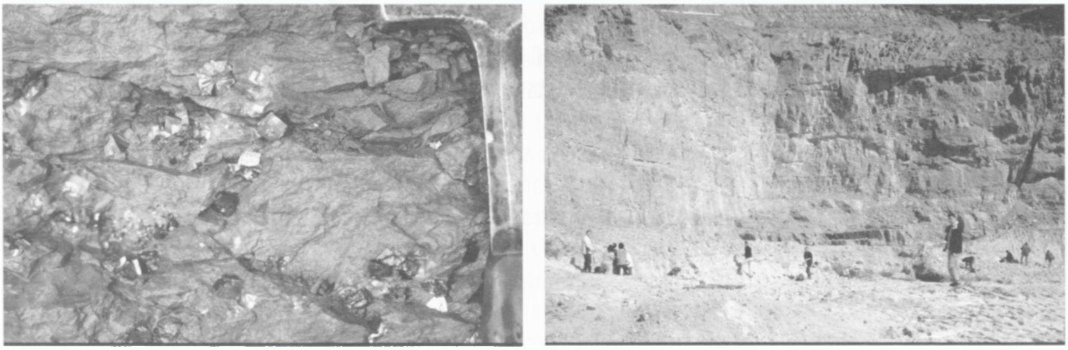


Figure 4. Navajún site and detail of pyrites.

These minerals develop in rocks of almost any composition, since they are in calcareous, in shales or in sandstones. The major minerals and with more complex forms are especially formed in the siliceous stratigraphic units of the Urbion Group.

There are different proposals about the origin of pyrites: volcanic, sedimentary and metamorphic. Without entering in the discussion about the origin of sulphur or the processes that other paragenetic minerals determine, there are several observation facts which show clear implications: 1) the distribution of deposits is not homogeneous to any scale; 2) the superposition in the same points of pyrite development and other metamorphic processes; 3) their universal distribution is not limited to a sedimentary environment, or to a certain type of sedimentary rock; 4) the age of the rocks with pyrites ranges between Jurassic marine limestones (between Ágreda and the Moncayo mountains) and the Group of Enciso shales, probably of Aptian age.

Pyrites have been considered magic stones and have been used to avoid the fall of beams and for disease treatment (the espántagos of San Juan). In Navajún's deposit there are single form crystals (cube and pyritohedron) with compound forms (cube+pyritohedrom, cube+octahedrom) macles and crystal groups.

REFERENCES

Alonso-Azcárate, J., Rodas, M., Bottrell, S.H. and Mas, J.R. 2002. Los yacimientos de pirita en la Cuenca de Cameros. In: Pérez-Lorente,F. (ed.), Aspectos naturalísticos de los Cameros. I. Geología. *Zubia momográfico*, 14, 173-190.

Blanco, M. I., Caro, S., Pérez-Lorente, F., Requeta, E. and Romero-Molina, M. 1999. Paleo-ichnological sites in La Rioja: some examples in Enciso, Igea and Munilla. In: The Geological and Paleontological Heritage of Central end Eastern Iberia (Iberian Range, Spain). *Seminario de Paleontología de Zaragoza*, 4, 51-74.

Brancas, R., Martínez, J. and Blaschke, J. 1979. *Huellas de dinosaurio en Enciso.* Gonzalo de Berceo, Logroño, 97 pp.

Caro, S. and Pavia, S. 1998. Alteración y conservación de los yacimientos de huellas de dinosaurio de La Rioja. "La Virgen del Campo" (Enciso) y la "Era del Peladillo" (Igea). *Zubía*, 16, 199-232.

Casanovas, L. and Santafé, J.V. 1974. Dos nuevos yacimientos de icnitas reptiles mesozoicos en la región de Arnedo. *Acta Geológica Hispánica*, 3, 88-91.

Casanovas, L., Pérez-Lorente, F., Santafé, J.V. and Fernández, A. 1985. Nuevos datos icnológicos del Cretácico inferior de la Sierra de Cameros (La Rioja). *Paleontología y evolució,* 19, 3-18

Casanovas, L., Fernández, A., Pérez-Lorente, F. and Santafé, J.V. 1989. Huellas de dinosaurio de La Rioja. Yacimientos de la Virgen del Campo, La Senoba y Valdecevillo. *Ciencias de la Tierra*, 12, 1-190.

Casanovas, M.L., Pérez-Lorente, F., Ruiz, M., Santafé, J.V. and Torcida, F. 1991. Terópodos carnosaurios en la Virgen del Campo II. Enciso (La Rioja, España). *Zubía*, 9, 113-126.

Ezquerra, R. and Pérez-Lorente, F. 2003. Reptiles nadadores en el sector oeste del yacimiento de la Virgen del Campo (4LVC, Enciso. La Rioja. España). In: Pérez-Lorente, F. (ed), Dinosaurios y otros reptiles mesozoicos de España. *Ciencias de la Tierra*, 26, 215-224.

Ezquerra, R., Costeur, L., Doublet, S., Galton, P.M. and Pérez-Lorente, F. 2004. Lower Cretaceous swimming theropod trackways from "La Virgen del Campo" (La Rioja, Spain). *Paleontological Association Annual Meeting.* Lille, Abstracts, p. 150.

Ezquerra, R., Doublet, S., Costeur, L., Galton, P.M. and Pérez-Lorente, F. 2007. Were non-avian Theropod dinosaurs able to swim? Supportive evidence from an Early Cretaceous trackway, Cameros Basin (La Rioja, Spain). *Geology*, 35, 507-510.

Mata, M. P. and López-Aguayo, F. 2002. La cookeita asociada a la pirita de la Cuenca de Cameros: estudio por microscopía electrónica de barrido y de transmisión. In: Pérez-Lorente, F. (ed.), Aspectos naturalísticos de los Cameros. I. Geología. *Zubia momográfico, 14*, 155-172.

Moratalla , J.J. 1993. *Restos indirectos de dinosaurios del registro español: paleoicnología de la Cuenca de Cameros (Jurásico superior-Cretácico inferior) y paleoología del Cretácico superior.* Ph.D. Thesis, Universidad Autónoma. Madrid, 728 pp.

Moratalla, J.J. and Sanz, J.L. 1992. Icnitas aviformes en el yacimiento del Cretácico inferior de Los Cayos (Cornago, La Rioja, España). *Zubía*, 10, 153-160.

Moratalla, J.J. and Hernán, J. 2008. Los Cayos S y D: dos afloramientos con icnitas de saurópodos, terópodos y ornitópodos en el Cretácico inferio del área de Los Cayos (Cornago, La Rioja, España). *Estudios Geológicos*, 64, 161-173.

Moratalla, J.J., Hernán, J. and Jiménez, S. 2003. Los Cayos dinosaur tracksite. An overview of the Lower Cretaceous ichno-diversity of the Cameros Basin (Cornago, La Rioja Province. Spain). *Ichnos*, 10, 229-240.

Pérez-Lorente, F. 2001. *Paleoicnología. Los dinosaurios y sus huellas en La Rioja. Apuntes para los cursos y campos de trabajo de verano.* Gobierno de La Rioja, Logroño, 227 pp.

Pérez-Lorente, F., Fernández, A. and Uruñuela, L. 1986. *Pisadas fósiles de dinosaurio. Algunos ejemplos de Enciso.* Gobierno de La Rioja, Logroño, 35 pp.

Pérez-Lorente, F., Romero-Molina, M., Requeta, E., Blanco, M. and Caro, S. 2001. Dinosaurios. Introducción y análisis de algunos yacimientos de sus huellas en La Rioja. *Ciencias de la Tierra*, 24, 1-102.

Sanz, J.L., Moratalla, J.J. and Casanovas, M.L. 1985. Traza icnológica de un dinosaurio iguanodóntido en el Cretácico inferior de Cornago (La Rioja, España). *Estudios Geológicos,* 41, 85-91

Valle, J.M. 1993. Metodología y resultado del levantamiento por fotogrametría terrestre del yacimiento de huellas de dinosaurio de Valdecevillo en Enciso (La Rioja). *Zubia monográfico,* 5, 165-186.

Viera, L.I. and Torres, J.A. 1979. El Weáldico de la zona de Enciso (Sierra de los Cameros) y su fauna de grandes reptiles. *Munibe,* 31, 141-0157

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

GEOLOGY AND ORE DEPOSITS OF PORTUGAL – A RECENT MARRIAGE

Manuel Serrano Pinto and António Soares de Andrade

GeoBioTec, Departamento de Geociências, Universidade de Aveiro, Portugal.
mspinto@ua.pt, asandrade@ua.pt

Abstract. When were the most important Portuguese ore deposits conceived as being the result of geological processes and not of processes exotic to them? How did such conceptions fit in the history of the main ideas on ore genesis? A historical review reveals that in Portugal: a) geology and ore deposits started to be "married" together only in the 1940s; b) the time gap between the appearance of innovative ideas on that topic and their application was usually a large one, the exception being plate tectonics and ore deposits in Southern Portugal (1972). In fact Aristotle's, Plato's and the Alchemists' ideas seem to be put in use in the 15th to the 17th centuries, only; Agricola's concepts seem to have been applied only in the 18th and 19th centuries; the first geologist to relate ore genesis and geological processes did so in 1861. In the 20th century the ideas of E. de Beaumont, L. Launay, W. Lindgren and others were applied only in the 1940s. From 1955 onwards individual efforts were replaced by the work of Dutch teams of geologists linking mining geology and metallogenesis.

1. INTRODUCTION

What follows is about the Portuguese ore deposits and tries to give some sort of answers to these two questions:

When were the most important Portuguese ore deposits conceived as being the result of geological processes and not of processes exotic to them?

How did such conceptions fit in the history of the main ideas on ore genesis?

So we need to know something about the geology of Portugal and about the location and nature of some of its ore deposits. If we look at maps of occurrences of useful minerals in Portugal, in general the old maps show the geological composition of the country (rock types and formations) in a hardly visible way, but at the same time one can see that the country is relatively rich in terms of such minerals (see, for instance Vianna, 1952). Décio Thadeu (1965) depicted the location of ore deposits ("mineralizações") against a geotectonic background, so approaching the relationship between geology and ore deposits in a better way. The most recent geological map of Portugal gives us a complete picture of the complex geology of the country (S.G.P., 1992) as well as the location of the most important mineralizations ("jazidas"), but no comments are available about the relationships between them and geology. From all these sources it is possible to conclude that:

a) Portugal's mineral resources are impressive for their variety but not for their output. In other words, the country lacks extensive deposits of valuable minerals of high quality, except in a few cases: 1) in Roman times the Iberian Peninsula was a big gold producer, with Portugal playing a major role; 2) the country had in the 1950s the largest uranium mine in Western Europe (Urgeiriça) and the world's largest tungsten mine

(Panasqueira) during WW II, and 3) the Neves-Corvo mine, in the Iberian Pyrite Belt, has been considered one of the top mines in Europe (Goínhas, 1987; Thadeu, 1989; Carvalho, 1994; D.G.G.M., 1998).

b) In Portugal, relating geology and ore deposits has not been a preoccupation. A good example is the biggest Portuguese encyclopaedia (Grande Enciclopédia Portuguesa e Brasileira), where no reference to Portuguese ore deposits is made in the entry "Jazigos minerais" and no reference to ore deposits is made in the entry "Geologia".

c) Given the importance that they have had in economic terms for the country and/or because they have been considered outstanding deposits, the following deposits are the ones to be mainly dealt with in the present paper: gold; tin and tungsten; iron and manganese; and copper, lead and zinc deposits of the Iberian Pyrite Belt.

2. A BRIEF HISTORY OF MINING IN PORTUGAL

Some facts related to the history of mining in Portugal are now presented, as well as to the general history of mining since that helps to answer the two questions posed above.

In Portugal there is abundant archaeological evidence of a Copper Age, a Bronze Age and an Iron Age (Ferreira da Silva, 1983).

In De Re Metallica (Agricola, 1950) several references are made to mining works carried out by the Lusitanians. Lusitania occupied the central part of Portugal and part of Western Spain, where gold was abundant. In past times the Tagus River, that has its mouth in Lisbon, was known as aurifer Tagus by certain classic authors, as Catulo for instance. Lusitania eventually became a Roman province and during the Roman occupation of the Peninsula (roughly from the 3rd century BC to the 7th century AD), important underground gold mining works were carried out in Northern Portugal and for copper in the Southern part of the country, namely in the Pyrite Belt. To a lesser extent, tin and lead were also mined by the Romans. Both copper and gold were mined from the oxidized and supergene enrichment zones of massive pyrite deposits; gold and cassiterite were won from river alluvium and gold and silver quartz vein deposits were also mined or prospected by the Romans (Allan, 1965; Thadeu, 1989). The Roman occupation of Iberia suffered the invasions of the Barbarians during which mining was halted and this was followed by the Arab occupation of the Peninsula, roughly from the 7th to the 13th centuries AD, during which only alluvial gold seemed to have been mined in Portugal. It is known that in the 14th century, efforts to exploit iron and alluvial gold were unsuccessful (Thadeu, 1989). The 15th and 16th centuries and to a lesser extent the 17th century were the centuries of the discoveries and maritime travels. The Portuguese looked for gold in Brazil and exploited it following methods that had been in use in Portugal for several centuries in the case of alluvial gold. In the 18th century, the Brazilian gold production was astonishingly high during the first half, but it decreased sharply in the second half (Pinto, 2000). From 1580 to 1640, the kings of Spain were also the kings of Portugal and certain aspects of gold mining in Brazil showed an Iberian influence (Vandelli, 1994).

3. IDEAS ABOUT THE ORIGIN OF THE ORE DEPOSITS

3.1 15th to the 17th centuries

Alphonso the fifth (1432-1481), king of Portugal between 1438 and 1481, wrote a treatise on how to convert quicksilver, lead and other metals into gold, giving a detailed description on how to do that (Alphonso King of Portugal, 1652). We are therefore in the presence of an example of the influence of alchemist's ideas on metals, which continued to prevail in the following centuries. Gaspar Frutuoso (1522-1591), a Portuguese vicar who lived in the Azores, wrote a manuscript between 1586 and 1590 (*Saudades da Terra*), where an excerpt about the origin of sulfur and saltpetre reads like this: *so we may say that the Earth sneezes out the vapor* [saltpetre and sulfur humors] *generated in excess in subterranean cavities by the sun and ignited may be by the action of some underground wind or exhalation.* So he follows Aristotle's ideas in that it was the sun rays that caused the concentration of sulfur, saltpetre, etc. But he seems also to follow Plato's ideas according to which in the centre of our planet there was a great fire that was kept going by penetrating sun rays. This conception —that the sun originated metals— led the Portuguese to believe that Brazil was richer in gold and silver than Spanish America because the sun rays were stronger there and reached Brazil before reaching the Andean countries (Solla, 1968). António Vieira (1608-1697), a Portuguese Jesuit preacher, believed that God had created the world with plants and animals for the benefit of Man, but that was not the case of minerals, and so mining should not be carried out in any way. Gold and silver veins if exploited might make men rich, but in the end that would punish them. He also thought that demons inhabited the Earth's interior, namely the deepest zones of mountains, which was therefore a place for the damnation of people. Similar conceptions were defended by the Spanish priest Alvaro Alonso Barba (1559-1662) in his *Arte de los Metales*, published in Madrid in 1640, where he wrote that God, the creator of the natural world, had hidden the metals deep in the Earth's interior in order to hinder human ambition. But, contrary to Vieira, who said simply that God had created metals, Barba explained their origin: a mixture of a humid and oily exhalation and of a viscous and thick earth was the matter that metals were made from.

Agricola (1950) classified the mineral deposits in alluvial and in situ deposits, according to their origin, and the latter classified according to their morphology, in fissure veins, bedded deposits, stockwerks or impregnations, stingers and seams or joints. He left us two fundamental propositions: a) the ore channels were of origin subsequent to their envelope rocks, and b) that the ores were deposited from solutions circulating in these openings. These are mid 16th century ideas that were not adopted in Portugal until the 18th century and only in part. In the 16th century it was already known in Portugal that gold occurred in veins and in alluvial deposits that derived from veins mostly by erosive action of running water, but instead the prevailing ideas about its primary origin in the 17th century were Plato's and Aristotle's and also the alchemist's (Picanço, 1997). Agricola's propositions were non-imaginable.

3.2 18th and 19th centuries

Those subjects were discussed at the University of Coimbra, reformed in 1772, and in the Lisbon Academy of Sciences, founded in 1779, where the Italian professor Domenico Vandelli (1735-1815) was an important figure from the scientific point of view. He knew about Agricola's works and in fact he wrote in 1779 a description of the morphology of the mineral veins that seems to be taken, at least in part, from De Re Metallica (Vandelli, 1779). Three of his former Coimbra students were sent to Freiberg and enrolled in the Mining Academy. One of them wrote in the first quarter of the 19th century that alluvial gold found near Lisbon, close to the Tagus River, might have been deposited there from sea water (Andrada e Silva, 1817). Werner's importance was kept in Portugal for several years and two members of the teaching staff of Coimbra University went to Freiberg in 1804: João António Monteiro and Paulino de Nola O. Sousa (Portugal Ferreira, 1998). So neither Agricola's ideas nor N. Steno's (1638-1686) or J. Charpentier's (1728-1805) innovative conceptions of the 16th, 17th and 18th centuries had any impact in Portugal.

One of the first, if not the first, in Portugal to relate ore genesis and geological processes was Carlos Ribeiro (1813-1882), a geologist who in 1861 considered some sulfide deposits (chalcopyrite, pyrite, galena, etc.) occurring in northern Portugal to be genetically related to veins of basic rocks (hypersthene diorites) (Ribeiro, 1861). So he is probably the first plutonist in Portugal as far as ore genesis is concerned, linking this to magmatic processes. As James Hutton (1726-1797) published his seminal work in 1795, his ideas were therefore applied in Portugal some 65 years after that.

Miranda Júnior (?-?), a Brazilian-born mining engineer working in Oporto, Portugal, as a member of the teaching staff of two technical institutions, presented in 1885 a classification of ore deposits according to A. von Groddeck (1837-1887), and a description of their origins compiled from many authors (Miranda Júnior, 1885). He pointed out the valuable experimental work of G.A. Daubrée (1814-1896), contradicted A.G. Werner's (1794-1817) ideas and applied some of the models of formation that he described to several Portuguese deposits.

3.3 20th century

We have to jump to the 1940s to see the ideas of Elie de Beaumont (1798-1874) (mid 1800s), L. de Launay (1860-1938) (late 1800s - early 1900), W. Lindgren (1860-1939) (first quarter of the 20th century) and others to be applied in Portugal; that is, ideas then already between some 20 to 100 years old.

Cotelo Neiva, a professor at Coimbra University, wrote extensively and in depth about the geology of many Portuguese ore deposits. As an example a long quotation is presented below (Table 1) where types, ages, mineralizations (tin, tungsten, gold, iron) and the respective mechanisms of the formation (mostly by magmatic differentiation, crystallization and segregation, except in the case of some manganese and hematite deposits thought to be of sedimentary origin) are dealt with (Cotelo Neiva, 1944). His expertise was in the field of the magmatic-hydrothermal deposits, but he also studied the ironstone-type Fe deposits, recognizing the importance of the stratigraphic control, the role of sedimentation in the initial concentrations of the element and the influence of the regional metamorphism on the paragenetic evolution. The uranium deposits were also studied by him, pointing out their relationship with granites and also the important role of remobilization in the secondary environment.

Another example is Décio Thadeu (1919-1995), a professor at the Technical University of Lisbon, who studied the Panasqueira cassiterite and wolframite mine and conceived the formation of the ores and other minerals according to a geochemical diagram created by Fersman (Thadeu, 1951). He was also aware of W. Lindgren's ideas as shown in the references of his paper.

Both authors (Neiva and Thadeu) kept writing about the mechanisms of formation of Portuguese ore deposits along lines similar to those presented in the forties and the fifties of the 20th century. They ended the "divorce" of interests that had always existed between geologists (in charge of "pure" geology) and mining engineers (in charge of ore deposits and mining geology). Neiva studied geology + ore deposits, while Thadeu studied ore deposits + geology (paleontology inclusive!), but they were perhaps isolated cases. Both became more and more interested in the age and geotectonic setting of the Portuguese ore deposits, that is, in relationship to the various orogenies or orogenic phases, the effects of which are seen in the Portuguese crust. Thadeu (1989), is a good example of such interest, for remarking the geologic ages (both chronostratigraphic and orogenic) of the most important ore deposits occurring in Portugal in the various geotectonic zones of the Hesperian Massif (Table 2).

1. They were four the main metallogenetic epochs of magmatic differentiation in Portugal, one of which was Permian, another Carboniferous, still another probably middle and upper Devonian, and finally one post Archean whose period is difficult to determine.
2. During the Permian epoch were formed the pegmatitic and hypothermal deposits of cassiterite and wolframite, the hypothermal deposits of scheelite, the pegmatitic deposits of Uranium and Radium ores, and the mesothermal deposits of sulphides, sometimes with gold and silver present. All those deposits resulted by differentiation of a granitic magma of calco-alkaline clan, and can be found in the Beiras, Douro-Litoral, Minho, Trás-os-Montes and Alto-Douro.
3. During the Carboniferous epoch were formed the mesothermal deposits of the piritous belt of Alentejo, resultant from residual solutions of the magma which gave origin to the majority of porphyries of the same province.
4. The magnetite deposits of Alentejo, both those of magmatic segregation as the pyrometasomatic ones, are conneted with magmatic intrusions of tonalite, diorite, gabro and seldom dolerite, rocks formed by crystallisation and differentiation of the same magma-body. I suppose the intrusions of this magma to have occurred during the Meso-Devonian. By differentiation and crystallisation of this magma were formed residual solutions which originated some mesothermal deposits of sulphides of Alentejo, perhaps during the Neo Devonian.
5. There was still another epoch during which were formed the deposits of cromite of Bragança and Vinhais; they are deposits of magmatic segregation, related to a peridotitic magma.
6. We suppose the deposits of Manganese ores and hematite of Alentejo to be of sedimentary origin, though lately transformed by hydrothermal metamorphism.

Table 1. Metallogenetic epochs of magmatic differentiation in Portugal (quoted from Cotelo Neiva, 1944, pp. 12-13).

The existence of several geotectonic zones in Iberia was established in the second half of the 1940s by F. Lotze (1903-1971) from a fixist, hercynotype perspective (Lotze, 1945) and by A. Schneider (?-?) from a mobilistic, alpinotype perspective (Schneider, 1947a, b). Based on his conceptions, the latter conceived a metalogenetic model for Cr, Fe-Ti, Cu-Zn-Pb-Ag-Sb-Au and As-Sn-W-Bi-Ag.

From 1955 onwards the individual efforts to linking mining geology and metallogeny were replaced in Portugal by the work by Dutch teams of geologists studying the Central Iberian Zone (e.g. Schermerhorn, 1956) and the South Portuguese Zones (e.g. Boogaard, 1967). As for mineralizations in Southern Portugal, including the Portuguese sector of the Iberian Pyrite Belt, Fig. 1 shows their location as well as the distribution of various igneous rocks that occur there (Carvalho, 1972).

<table>
<tr><th colspan="2">Chronology</th><th>West Asturian-Leonese Zone</th><th>Middle Galicia-Trás-os-Momes Zone</th><th>Central Iberian Zone</th><th>Ossa-Morena Zone</th><th>South Portuguese Zone</th></tr>
<tr><td>POST-HERCYNIAN</td><td>MESOZOIC?</td><td></td><td></td><td>Base-metal quartz vein deposits Au-Sb quartz vein deposits U ore deposits URGEIRIÇA, NISA</td><td></td><td>Fe-Mn deposits</td></tr>
<tr><td rowspan="4">HERCYNIAN</td><td rowspan="3">PERMIAN</td><td rowspan="3">Sn quartz vein deposits MONTESINHO</td><td></td><td>Ag-Pb-Zn quartz veindeposits</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td colspan="2">Au-Ag quartz vein deposits JALES Scheelite-wolframite skam deposits VALDARCAS Sn-W quartz vein dcposits* PANASQUEIRA, ARGOZELO, BORRALHA</td></tr>
<tr><td>Nb-Ta-Sn aplite-pegmatites</td><td>Sn- Li- De pegmatites</td></tr>
<tr><td>LOWER CAROONIFEROUS</td><td></td><td></td><td></td><td></td><td>Mn volcanogenic-sedimentary deposits Volcanogenic-sedimentary complex sulphide deposits ALJUSTREL, NEVES-CORVO</td></tr>
<tr><td rowspan="4">PRE-HERCYNIAN</td><td>UPPER SILURIAN</td><td></td><td></td><td></td><td>Fe volcanogenic-sedimentary deposits ORADA</td><td></td></tr>
<tr><td>LOWER ORDOVICIAN</td><td>Bedded iron in quartzites GUADRAMIL</td><td></td><td>Belded iron in quartzites MONCORVO</td><td></td><td></td></tr>
<tr><td>LOWER CAMBRIAN</td><td></td><td></td><td></td><td>Polymetallic sulphites Zn- Pb- Cu) in dolomitic beds PREGUIÇA</td><td></td></tr>
<tr><td>PRECAMBRIAN</td><td></td><td>Cr in ultramafics BRAGANÇA-VINHAIS</td><td></td><td></td><td></td></tr>
</table>

* In the Ossa-Morena Zone only northwards of Juromenha fault.

Table 2. Mineral deposits of Hesperian Massif listed in tentative chronological sequence (Thadeu, 1989, p. 202).

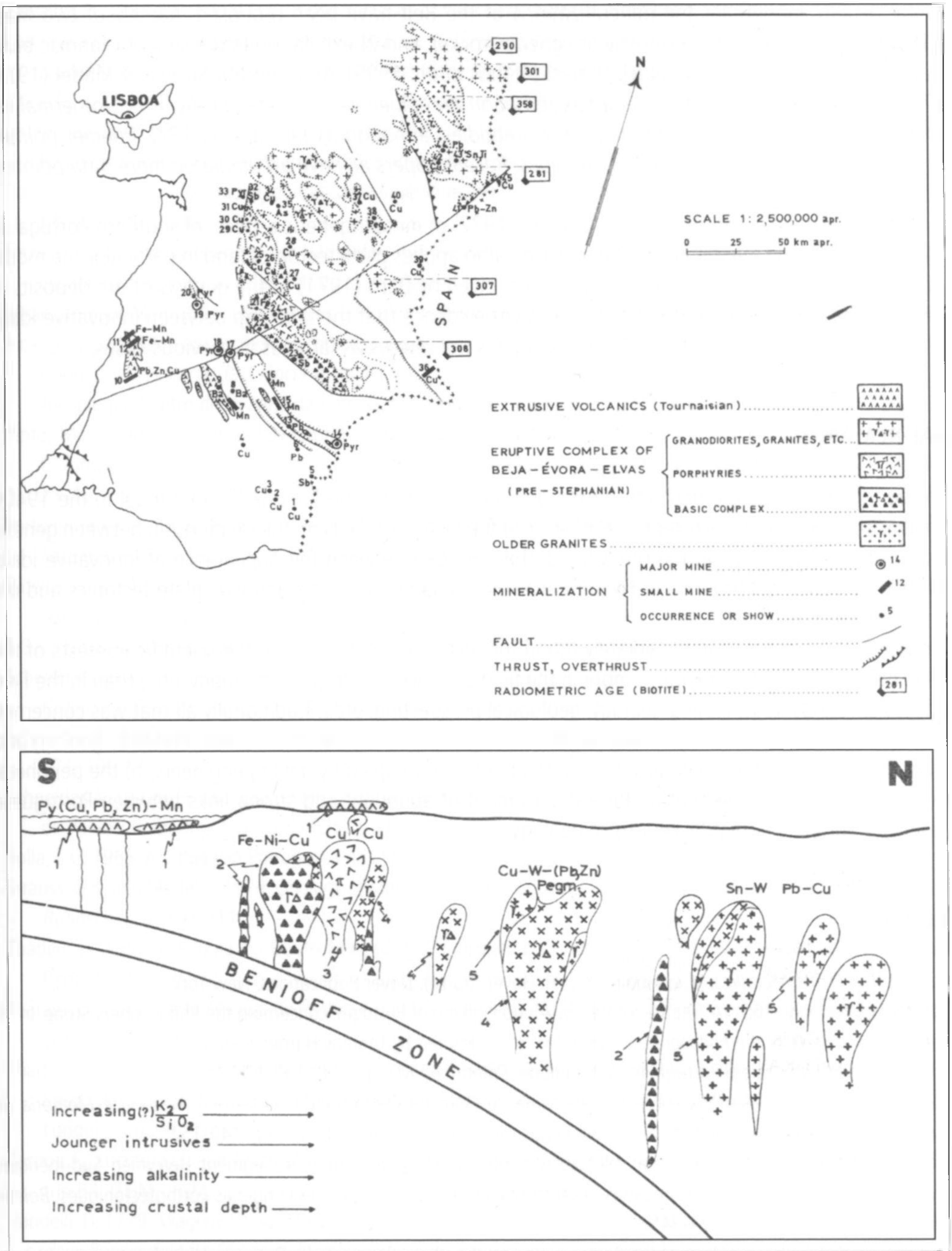


Figure 1. Distribution of mineralization and magmatic evolution in southern Portugal
(after Carvalho, 1972, pp. 310 and 312).

Several genetic models for the mineralizations of the Belt have been proposed, namely of two main types: 1) synvolcanic replacement (mostly on igneous rocks), and 2) exhalation in the seafloor (anoxic brine pools; above igneous rocks and in black shales) (Tornos et al., 1999). According to Strauss & Madel (1974, p. 193) *"Prior to 1960 most authors emphasized upon an epigenetic and, specifically, a hydrothermal replacement origin for the pyrite and manganese orebodies, although as far back as 1872 Roemer pointed out the syngenetic sedimentary nature of ore types. Recent papers all have accumulated more data pointing to the syngenetic*

Fig. 1 shows also an interpretation by Carvalho (1972) of metallogenetic aspects of southern Portugal at the light of plate tectonics. In his seminal paper, Carvalho applies plate tectonics (and in particular the model of the Hercynian chain for the Iberian Peninsula conceived by Bard (1971) to the genesis of ore deposits in Southern Portugal, including the Pyrite Belt. This gives evidence that the time gap between innovative ideas (plate tectonics in the case) and their use in Portugal is not always as large as in previous cases.

4. FINAL REMARKS

In conclusion, geology and ore deposits, on the one hand, started to be "married" in Portugal in the 1940s, which makes such "marriage" a recent one in terms of the history of ideas on the relationship between genesis of ore deposits and geology. On the other hand, the time gap between the appearance of innovative ideas on that topic and their applications in Portugal was usually large. The exception was plate tectonics and ore deposits in Southern Portugal.

A couple of reasons may be immediately found for such late "marriage": a) the scientific interests of the geologists before the 1940s were much more in the field of "pure" geology (stratigraphy, etc.) than in the field of ore deposits (ore geology, mining geology, geological prospecting, etc.). Traditionally all that was concerned with ore deposits was dealt with by mining engineers; also important government posts related to geology and mines, like the director of the Geological Survey, tended to be occupied by mining engineers; b) the peripheral position of Portugal did not help at all the establishment of abundant and strong links between Portuguese geologists and European scientific centres of geology.

REFERENCES

Agricola, G. 1950. *De Re Metallica.* H. C. Hoover & L. H. Hover (transl). Dover Publications, New York.

Alphonso King of Portugal, 1652. A Treatise written by Alphonso king of Portugal, concerning the Philosophers Stone. In: H. P. (ed.), *Five Treatises of the Philosophers Stone. Two of....* Printed by Thomas Harper, London, 1-9.

Allan, J.C. 1965. A Mineração em Portugal na Antiguidade. *Boletim de Minas,* 2 (3), 139-175.

Andrada e Silva, J.B. 1817. Memória sobre a Nova Mina de Ouro da Outra banda do Tejo. In: *História e Memória da Academia Real das Ciências de Lisboa.* Academia das Ciências de Lisboa, Lisboa, V, pp. 140-152.

Bard, J.P. 1971. Sur l'Alternance des Zones Métamorphiques et Granitiques dans le Segment Hercynien Sud-Ibérique. Comparaison de la Variabilité des Caractères Géotectoniques de ces Zones avec les Orogènes «orthotectoniques. *Boletín Geológico y Minero,* 82(3-4), 324-345.

Boogaard, M. van den, 1967. *Geology of the Pomarão Region (Southern Portugal).* Ph.D. thesis, Univ. Amsterdam, 113 pp.

Carvalho, D. 1972. The Metallogenetic Consequences of Plate Tectonics and Upper Palaeozoic Evolution of Southern Portugal. *Estudos, Notas e Trabalhos do S.F.M.,* XX, 3-4, 297-320.

Carvalho, D. 1994. Passado e Futuro dos Recursos Minerais em Portugal. *Colóquio/Ciências*, 14, 49-69.

Cotelo Neiva, J.M. 1944. Épocas de Metalogenia de Diferenciação Magmática em Portugal. *Publicações do Museu e Laboratório Mineralógico e Geológico da Faculdade de Ciências do Porto*, 39, 2ª S., Reprint, 13 pp.

D.G.G.M. (ed.) 1998. Neves-Corvo: um Projecto Mineiro de Importância Mundial. *Boletim de Minas*, 25, 157-166.

Ferreira da Silva, A.C. 1983. A Idade dos Metais em Portugal. In: J. H. Saraiva (dir.), *História de Portugal*. Selecções do Reader's Digest, SARL© (ed), Publicações Alfa SARL., Lisboa, 1, 101-148.

Goínhas, J. 1987. Cadre Géologique et Métallogénique des Ressources Minières du Portugal. *Chronique de la Recherche Minière*, 489, 25-42.

Lotze, F. 1945. Zur Gliederung der Variszіden der Iberischen Meseta. *Geotektonische Forschungen*, 6, 78-92. (Spanish version by J. M. Rios, in *Publ. Estranj. Geol. España*, V.)

Miranda Júnior, M. R. 1885. *Classificação e Modos de Formação dos Jazigos Metalliferos*. Magalhães e Moniz-Editores, Porto.

Picanço, J.L., 1997. Concepções seiscentistas e setecentistas sobre a formação de depósitos de ouro aluvionar no Brasil colonial. In: *História da Ciência e da Tecnologia, Caderno de Resumos*. Convenção USP em História da Ciência e Tecnologia, Centro de História da Ciência, Universidade de São Paulo, São Paulo, 55.

Pinto, M. S. 2000. Aspectos da História da Mineração no Brasil Colonial. In: F. A. F. Lins, F. E. V. L. Loureiro, G. A. S. C. Albuquerque (Eds.), *A Construção do Brasil e da América Latina pela Mineração*. CETEM/MCT, Rio de Janeiro, 23-40.

Portugal Ferreira, M. R. 1998. *200 Anos de Mineralogia e Arte de Minas: desde a Faculdade de Filosofia (1772) até à Faculdade de Ciências e Tecnologia*. Fac. Ciências e Tecnologia, Universidade de Coimbra, Coimbra.

Ribeiro, C. 1861. Memória sobre o Grande Filão Metalífero que passa a Nascente de Albergaria-a-Velha e de Oliveira-de-Azeméis. *Memórias da Academia Real de Ciências de Lisboa*, N. S., 2, (II), 5-105.

S.G.P., 1992. *Carta Geológica de Portugal à Escala 1:500 000, 5ª edição*. Serviços Geológicos de Portugal, Lisboa.

Schermerhorn, L.J.G. 1956. Igneous, Metamorphic and Ore Geology of the Castro Daire – S. Pedro do Sul – Sátão area. *Comunicações dos Serviços Geológicos de Portugal*, XXXVII, 5-617.

Schneider, A. 1947a. Prospecção Mineira e Zonas Geotectónicas na Metalogénese Ibérica. I Parte – Introdução. *Técnica*, 171, 199-18.

Schneider, A. 1947b. Prospecção Mineira e Zonas Geotectónicas na Metalogénese Ibérica. II Parte – As Zonas Geotectónicas da Península Ibérica. *Técnica*, 176, 522-540.

Solla, L.C. 1968. A influência Portuguesa nas Minas do Brasil. 1500-1822. *Boletim de Minas*, V (2), 69-87.

Strauss, G.K. and Madel, J. 1974. Geology of Massive Sulphide Deposits in the Spanish – Portuguese Pyrite Belt. *Geologische Rundschau*, 1, 191-211.

Thadeu, D. 1951. Geologia do Couto Mineiro da Panasqueira. *Comunicações dos Serviços Geológicos de Portugal*, 32, Reprint, 64 pp.

Thadeu, D. 1965. *Carta Mineira de Portugal na Escala de 1/500 000*. Notícia Explicativa. Serviços Geológicos de Portugal, Lisboa.

Thadeu, D. 1989. Portugal. In: F. W. Dunning, P. Garrad, H. W. Haslam, R. A. Ixer (eds.), *Mineral Deposits of Europe*, Vol. 4/5: South West and Eastern Europe with Iceland. The Institution of Mining and Metallurgy & The Mineralogical Society of London, London, 197-220.

Tornos, F., Locutura, J. and Martins, L. (eds.) 1999. *The Iberian Pyrite Belt*. Joint SGA IAGOD International Meeting, Field trip B4. ITGM - IGM.

Vandelli, D. 1779. *Viagens Filosoficas ou Dissertação sobre as Importantes Regras que o Naturalista nas suas Peregrinações deve Principalmente Observar*. Academia das Ciências de Lisboa [ms]. Copied by Fr. Vicente Salgado in 1796. Academia das Ciências de Lisboa, Lisboa: Ms 405 V.

Vandelli, D. 179×. Memória sobre a Casa da Moeda e Prejuízo que Sofre a Real Fazenda e o Público por Falta dos

Conhecimentos Químicos. In: J. Vicente Serrão (dir.), *Domingos Vandelli, Aritmética Política, Economia e Finanças.* Banco de Portugal, Lisboa, pp. 85-90, 1994.

Vianna, A. 1952. *Carta Mineira de Portugal. Escala 1/1 500 000 (1929).* Comunicações dos Serviços Geológicos de Portugal. Suplem. Tomo XXXII. Serviços Geológicos de Portugal, Lisboa.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

THE RODALQUILAR CALDERA COMPLEX AND ASSOCIATED GOLD-SILVER AND ALUNITE DEPOSITS

Antonio Arribas Rosado

Newmont Mining Corporation, Greenwood Village, Denver (USA).
antonio.arribas@newmont.com

Abstract. Pb-Zn-(Ag-Cu-Au) and Au-(Cu-Te-Sn) epithermal deposits occur near the town of Rodalquilar, within the Rodalquilar volcanic caldera complex, which occupies the central part of the Cabo de Gata volcanic field of southeastern Spain. Both types of deposits are related to magmatic-hydrothermal processes that followed the emplacement of andesitic magma during the waning stages of the Rodalquilar caldera cycle. The Au-(Cu-Te-Sn) deposits are the most important economically and are preferentially localized in caldera collapse structures of a smaller, nested Lomilla caldera. High-grade gold ore occurs in silicified hydrothermal breccias and in black (pyritic) banded chalcedony that fills open spaces and fractures within volcanic rocks previously altered to argillic and advanced argillic assemblages. These deposits formed near the paleo-surface within a limited vertical span (<200m) and are typical of high sulfidation epithermal systems.

1. INTRODUCTION

The Rodalquilar gold and alunite deposit in the Sierra del Cabo de Gata, southeastern Spain, is an example of caldera related high-sulfidation type mineralization. This type of deposit is characterized by the presence of alunite [$KAl_3(SO_4)_2(OH)_6$] within zones of hypogene advanced argillic alteration, which results from the reaction of volcanic rock and extremely acidic fluids that are oxidized and have high sulfur content.

The Sierra del Cabo de Gata consists of Miocene calc-alkalic volcanic rocks of the Tertiary-Pleistocene Almeria-Cartagena volcanic belt, which extends north for about 150 km as isolated exposures of shoshonitic, lamproitic, and basaltic rocks (Fig. 1). The Cabo de Gata volcanic field is separated from the Paleozoic to Early Triassic metasedimentary basement by a prominent left lateral strike-slip fault. Recent studies suggest that the Almeria-Cartagena volcanic belt was formed during an episode of crustal thinning due to post-collisional collapse, following the main event of Alpine compression between Africa and Iberia.

Volcanic rocks in the vicinity of the Rodalquilar deposit range in composition from pyroxene andesite to rhyodacite and in age from about 15 to 7 Ma. The gold-alunite deposits are located within the Rodalquilar caldera complex and are closely associated with an extensive zone (over 25 km^2) of argillically and advanced argillically altered rocks (Fig. 2). By contrast, in the area of the Los Frailes caldera, a few km to the south (Fig. 3), the only evidence of hydrothermal alteration is the presence of small bentonite deposits. Thus, the magnitude and nature of hydrothermal activity in both calderas contrasted significantly. Several features that occur in the Rodalquilar caldera may have contributed to the existence of ore deposits within it. These include, the predominance of dacitic/rhyolitic magmatism and pyroclastic eruptions, the abundance of permeable zones

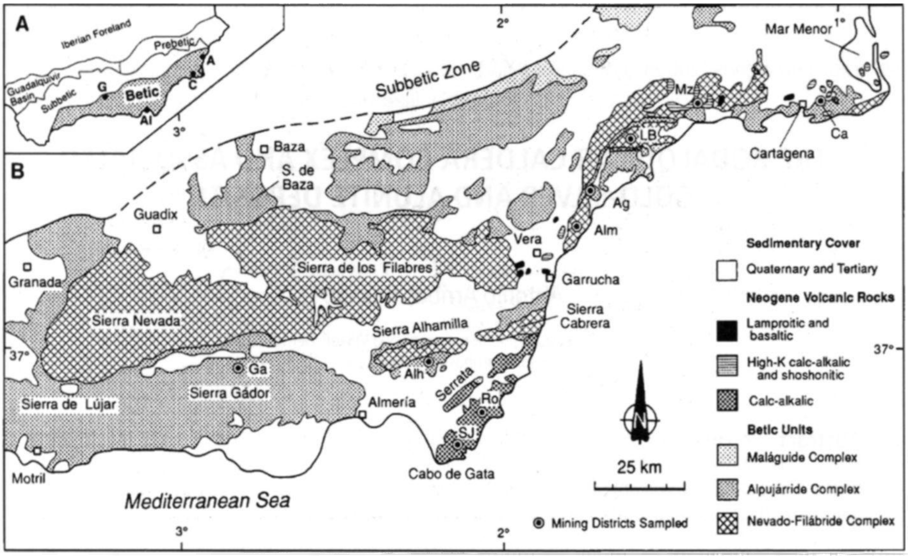


Figure 1. A) Tectonic subdivisions of the Betic Cordillera in Southern Spain. A = Alicante, Al = Almería, C = Cartagena, G = Granada. B) Lithotectonic map of the eastern Betic Zone showing location of the Miocene Cabo de Gata volcanic field and the Rodalquilar (RQ) deposits. Other base- and precious-metal deposits in the region include: Sierra de Gádor (Ga), Sierra Alhamilla (Alh), San Jose (SJ), Sierra Almagrera (Alm), Aguilar (Ag), Loma de Bas (LB), Mazarrón (Mz) and Cartagena (Ca).

along fractures related to multistage caldera collapse and resurgence, and the emplacement of a heat source at depth (Rytuba et al., 1990). Conversely, the Los Frailes caldera volcanism was predominantly andesitic/dacitic, pyroclastic eruptions were not as common, and, most importantly, favorable permeable zones may have been sealed by massive dacite domes that filled the caldera (Cunningham et al., 1990).

Gold has been mined in Rodalquilar since the end of last century and the Cinto deposits, investigated by ADARO, produced about 5 tonnes of Au between 1943 and 1966. In 1989, St. Joe Transacción started a heap-leaching operation at Rodalquilar for recovery of about 750,000 tonnes of ore at an average grade of 2.2 g/t of Au (Arribas et al., 1995). All mining operations are presently closed. Lead, Zn and Ag have been produced in the area, chiefly from mines in the San Jose district located SW of the Los Frailes caldera (Fig. 1B). Prior to the base- and precious-metal deposits, mining in area around Rodalquilar started in the early 1500s, as alunite veins and advanced argillically altered rocks were mined for the production of alum (Hernández, 2002).

2. THE RODALQUILAR AND LOMILLA CALDERAS

The Rodalquilar caldera is an oval collapse structure (dimensions 4 x 8 km) that was developed on an older andesitic volcanic field (Fig. 3). Precaldera domes of age 11.1 ± 0.4 Ma place a lower age limit on the formation of the caldera which resulted from the catastrophic eruption of the rhyodacitic Cinto ash-flow tuff (Fig. 4A; Rytuba et al., 1990). Resurgence in the core of the caldera resulted in the structural doming of intracaldera breccias and tuffs, and emplacement of large ring domes along the structural margin. Continued resurgence

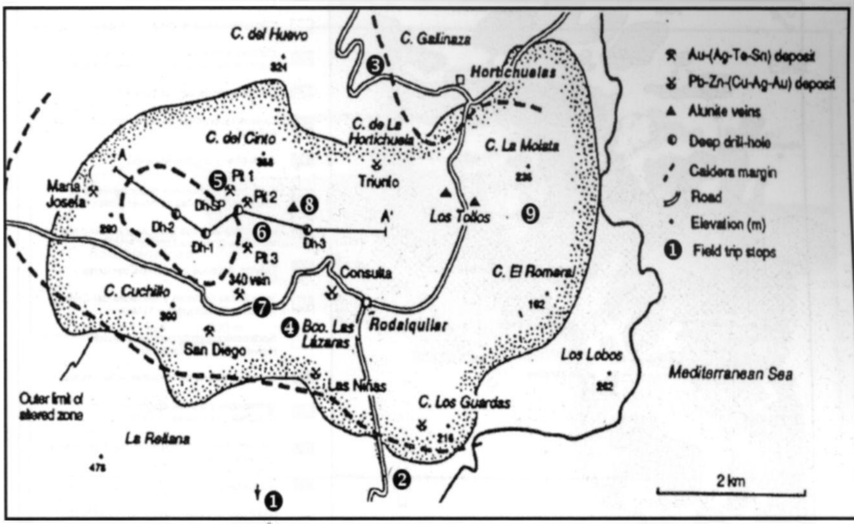


Figure 2. Map of the Rodalquilar caldera showing approximate location of mineral deposits, field trip stops, and the extent of altered rocks.

culminated in the eruption of the Lázaras ash-flow tuff and development of the 2 km diameter Lomilla caldera, nested within the resurgent dome of the Rodalquilar caldera. The Lázaras tuff and volcaniclastic and lacustrine sediments fill the moat of the Rodalquilar caldera. The next phase of volcanic activity in the caldera was the emplacement of hornblende andesite plugs and associated flows. This resulted in structural doming, opening of fractures and faults, and the development of large hydrothermal systems which formed the gold-alunite and base-metal vein systems. Only some of the hornblende andesite flows present in the Rodalquilar caldera are altered and mineralized, suggesting that mineralization occurred during the early phase of andesitic volcanism but ended before the last flows were emplaced at 9.0 ± 0.6 Ma (Rytuba et al., 1990). The last volcanic event within the Rodalquilar caldera was the emplacement of pyroxene andesite flows and breccias between 8.4 and 7.5 Ma (Fig. 3, 4A).

3. ORE DEPOSITS AND ASSOCIATED ALTERATION

Ore deposits within the Rodalquilar caldera complex consist of intermediate-sulfidation Pb-Zn-(Cu-Ag-Au) veins and high-sulfidation Au-(Cu-Te-Sn) ores, which include veins, hydrothermal breccias and disseminated deposits (Arribas et al., 1995). The Au-(Cu-Te-Sn) ores are the economically most important and have been the focus of most studies in the area.

3.1 Intermediate-sulfidation Pb-Zn-(Cu-Ag-Au) veins

Several base-metal quartz veins occur peripherally around the central core of hydrothermally altered rocks along north-south trending faults which transect all volcanic units within the Rodalquilar caldera complex

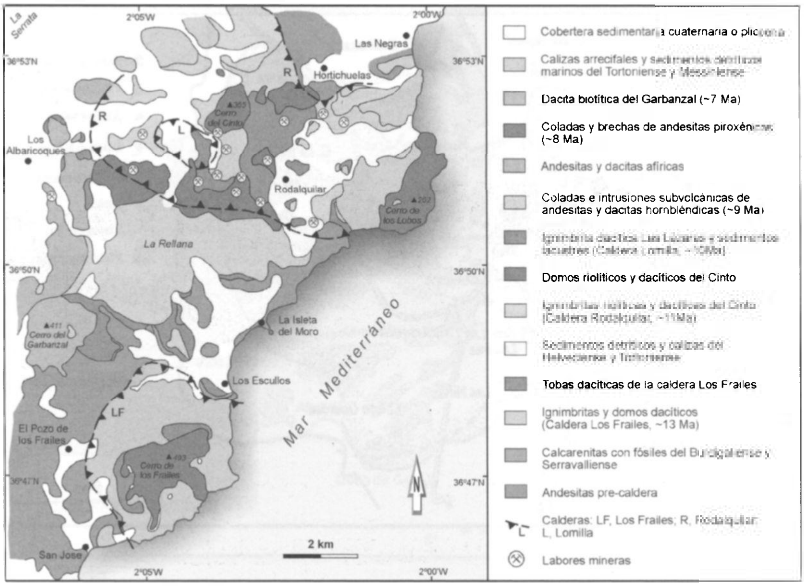


Figure 3. Geologic map of the Rodalquilar caldera complex (Arribas, 1993).

except the youngest pyroxene andesite flows. The Consulta vein (Fig. 2) near the town of Rodalquilar is representative of this type of veins and is characterized by pockets of massive galena in a gangue of banded crystalline quartz and opaline silica layers. The vein extends for about 1.5 km southward from the central part of the Rodalquilar caldera and grades outside the caldera into narrow veins of barren amethystine quartz. The ore assemblage includes sphalerite, chalcopyrite, pyrite, covellite, chalcocite, and locally native Au and bismuthinite. No alunite or adularia have been identified in the veins, but small amounts of chlorite and hematite are typically present. Stratigraphic constraints indicate that the intermediate-sulfidation veins are contemporaneous, within a maximum of 2 m. y., with the gold deposits in the center of the caldera.

3.2 +Gold-(Cu-Te-Sn), high-sulfidation-type deposits

The Au-(Cu-Te-Sn) deposits are preferentially localized in fractures present in the east wall of the Lomilla caldera. The host rocks are intracaldera ash-flow tuffs interbedded with collapse breccias but the northernmost deposits are partly hosted by a rhyolite ring dome. The deposits are restricted to the zones of intensely altered rock, chiefly within the zones of vuggy silica or advanced argillic alteration. None of the mine workings extended below 80-100 m. Below that depth, mineralized structures narrowed considerably and gold grades fell sharply. Deep drilling in the core of altered rock has shown that hydrothermally altered rocks continue to depths of over 900 m (Fig. 4B), and grade from a deep sericitic zone (quartz+sericite+pyr-ite) upward into intermediate argillic (quartz+kaol-inite+illite+illite-smectite+pyrite), advanced argillic (quartz+alunite+kaolinite+pyrophyllite+zunyite), and silicic (vuggy silica) zones (Figs. 5, 6; Arribas et al., 1995). The distribution of alteration zones indicate a funnel shape for the hydrothermal plumes. Two types of alunite characterized by contrasting paragenetic and isotopic characteristics define two differing environments of alunite formation. Stage 1 alunite is hypogene and formed in the volcanic hydrothermal environment, its isotopic composition was dominated

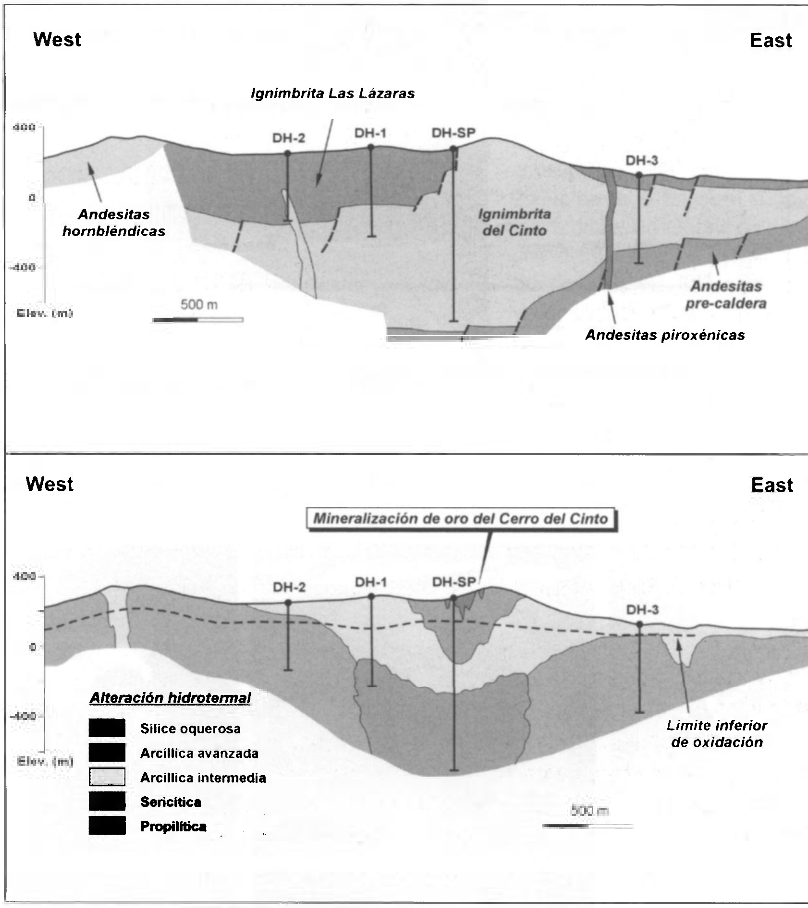


Figure 4. Cross-sections showing geology and alteration in the Rodalquilar caldera complex (modified from Arribas et al., 1995).

by magmatic fluids (Fig. 6A,B). Stage 1 alunite occurs in the core of the hydrothermal system and is closely associated with the zones of vuggy silica. Isotopic temperature estimates from Stage 1 alunite-pyrite pairs range from 220 to 330°C (Fig. 6A). Temperatures for the deeper portions of the hydrothermal system were higher, 350° to 450°C, based on fluid inclusion homogenization temperatures, and salinities which in some samples from the sericitic zone exceed 40 wt% NaCl equivalent. K-Ar ages of Stage 1 alunite and sericite collected from altered intracaldera tuffs all yielded comparable ages that average 10.4 Ma (Arribas et al., 1995). This age is consistent with stratigraphic constrains.

Gold mineralization in the high-sulfidation-type deposits occurred in the high portion of the central core of the hydrothermal system following the episode of acidic fluids that formed vuggy silica and hypogene Stage 1 alunite. The most important types of mineralization are hydrothermal breccias enriched in Te and Sn and chalcedonic quartz veins (Fig. 7C). The chalcedony veins represent a very irregular type of ore, both in form

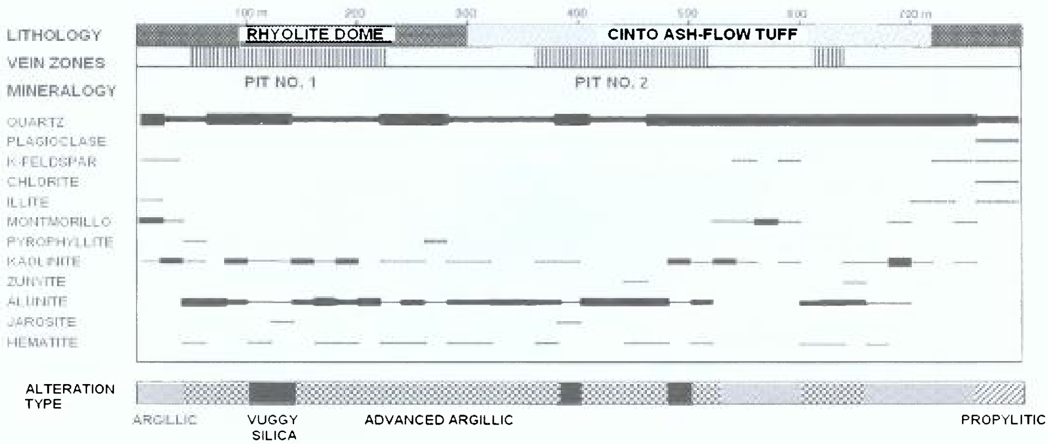


Figure 5. Schematic distribution of alteration assemblages in a NW-SE cross-section of the Cinto deposits along the 270-m bench.

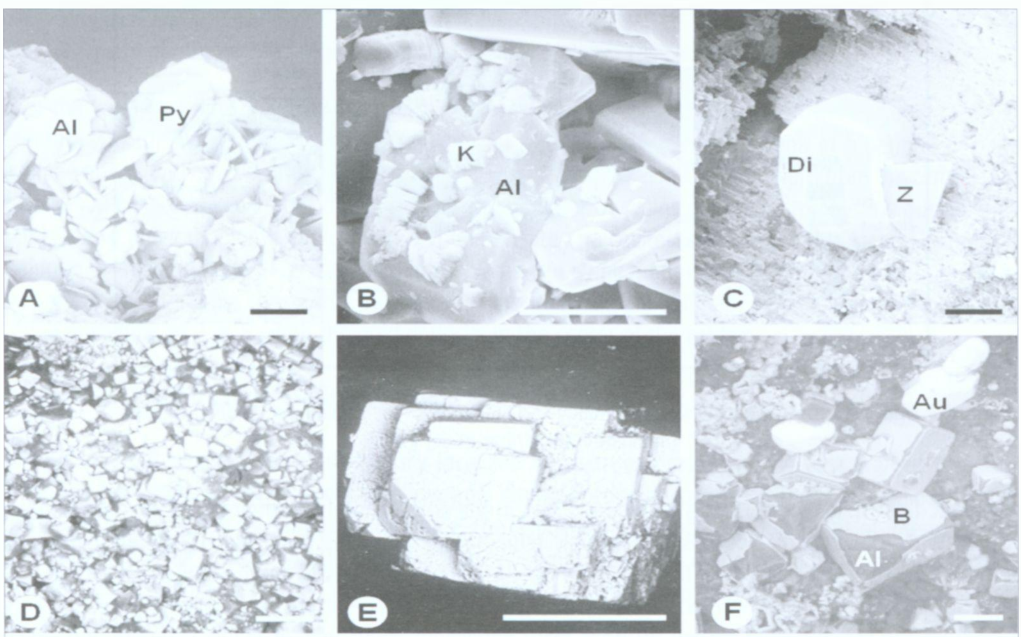


Figure 6. Scanning electron micrographs of selected alteration and mineralization assemblages in Rodalquilar. A. Pyrite (Py) and tabular Stage 1 alunite (Al) in hypogene advanced argillically altered rock (formation temp. based on Δ34Ssulfate-sulfide = 250-280°C). B. Alunite (Al) and kaolinite (K). C. Diaspore (Di) and zunyite (Z) in cavity of vuggy silica. D, E. Fine-grained pseudocubic alunite crystals. This morphology has exclusively been observed in Stage 2 alunite and differs markedly with that observed in Stage 1 alunite. F. Gold (Au) crystals and crusts and sphellurites of colloform iron tellurite (B; blakeite?) coating pseudocubic alunite crystals (Al). Bar scale represents 100 microns in photos A, B and C, and 10 microns in photos D, E and F.

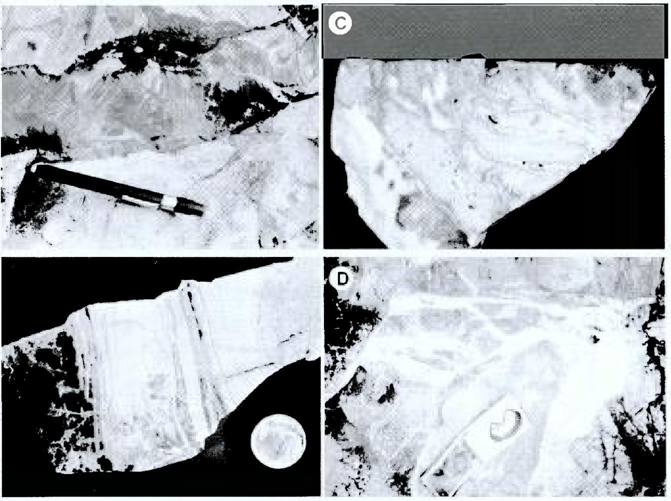


Figure 7. A and B. Aspects of banded chalcedony ore at Rodalquilar. A. Fracture filled with Au-bearing black (sulfide-rich), horizontally banded chalcedonic quartz. Some layers appear light in color due to weathering of sulfides. Average grade of the vein is 15g/t Au. The Au content of the vuggy silica envelope is 1.3 g/t. Sample 877A171, Cinto pit 1, 290-m bench. B. Fragment of oxidized chalcedonic quartz displaying intricate silica layering and breccia and detrital layers. C. High grade hydrothermal breccia from the 340 vein. Lithic fragments of vuggy silica, advanced argillically altered rock and banded chalcedony enclosed in a matrix of white chalcedony. Gold mineralization occurred following hydrothermal brecciation, as shown around lithic fragments. D. Fractures filled with beige-light yellow, supergene alunite (Stage 2 alunite, plus minor jarosite). Cinto pit no. 1.

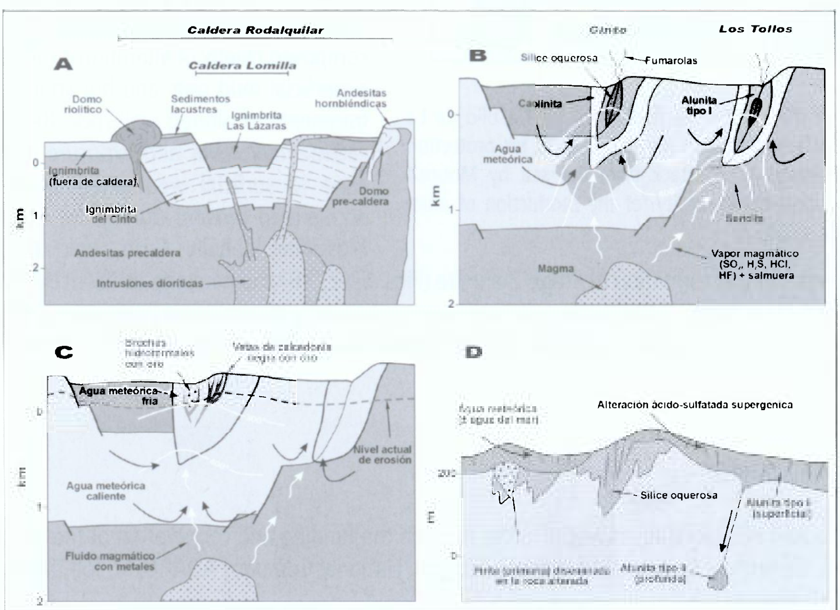


Figure 8. Schematic cross-sections showing the evolution of the Rodalquilar caldera complex and associated Au and alunite deposits. A. Geologic relations among lithologic units in the Rodalquilar caldera. Hydrothermal alteration affects all units except andesite flows outside the caldera. B. Main wall-rock alteration assemblage (age ~10.4 Ma) of the magmatic-hydrothermal systems responsible for the high-sulfidation deposits. C. Main Au mineralization stage of the magmatic-hydrothermal system. The estimated depth of the present-day erosion surface is shown by the dashed line. D. Supergene acid-sulfate stage (age 4-3 Ma) that led to the formation of stage 2 alunite and remobilization of the primary Au mineralization. Note, vertical scales are only approximate and are different for A, B and C, and D.

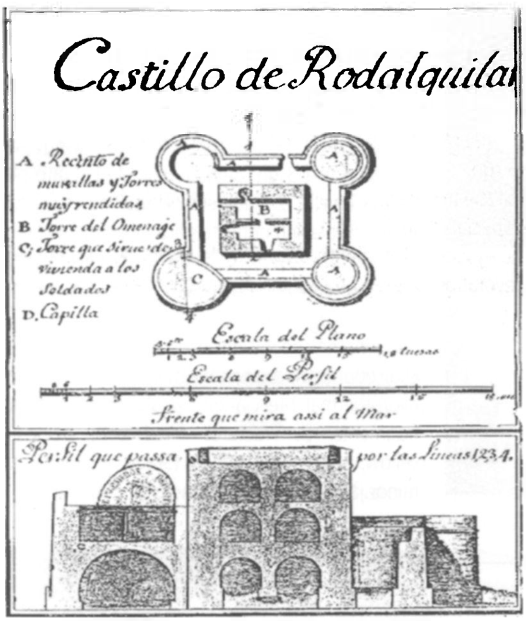


Figure 9. Plan of the Castillo de Rodalquilar or Castillo de La Hermita. This castle was built in the early 1500s for protection of the alum workings from attack from the sea by Moorish pirates and as a processing facility for the production of alum (Hernández Ortiz, 2008).

and grade, but they are the most representative of the Rodalquilar deposits. Generally, black, pyritic, banded chalcedony fills preexisting open spaces and fractures within rock previously altered to vuggy silica (Fig. 7A, B). This type of silica-sulfide precipitate is not dissimilar to silica sinter found in hot spring deposits and is suggestive of formation at very shallow depths. Based on measured O^{18}/O^{16} values for black chalcedony and assuming original deposition as amorphous silica, this type of ore formed from fluids dominated by meteoric waters at temperatures between 120 and 180°C. Economic mineralization is also found in vuggy silica and in some samples of advanced argillically altered rock close to the veins.

The collapse of the hydrothermal system resulted in the filling of open fractures, fumarolic conduits, and discharge channels, by sediments composed chiefly of alteration minerals from the superficial mud pots and hot-springs and lithic fragments of altered wall rock. Removal of the sedimentary cover and exposure of the sulfide zone to surficial weathering, in response to accelerated erosion during the Mediterranean Messinian Salinity Crisis, lead to supergene acid-sulfate alteration and formation of Stage 2 alunite (Figs. 6D-E, 7E) and kaolinite at about 3.5 Ma (Arribas et al., 1995). The mineralogy of the primary Au ores was significantly altered during this period (Fig. 6F). The evolution of the Rodalquilar caldera complex and associated Au-Ag and alunite deposits in shown schematically in Fig. 8.

ACKNOWLEDGEMENTS

The study of the Rodalquilar deposits was possible through the funding and cooperation of the US-Spain Joint Committee, U.S. Geological Survey, University of Michigan, National Company ADARO, St. Joe Transacción, and University of Salamanca.

REFERENCES

Arribas, A. Jr., Cunningham, C.G., Rytuba, J.J., Rye, R.O., Kelly, W.C., McKee, E.H., Podwysocky, M.H. and Tosdal, R.M. 1995. Geology, geochronology, fluid inclusions, and isotope geochemistry of the Rodalquilar Au-alunite deposit, Spain. *Economic Geology*, 90, 795-822.

Arribas Jr., A. 1993. *Mapa geológico escala 1:25,000 del distrito minero de Rodalquilar, Almería.* Instituto Geológico y Minero de España, Madrid.

Cunningham, C.G., Arribas Jr., A., Rytuba, J.J., and Arribas, A. 1990. Mineralized and unmineralized calderas in Spain; Part I, evolution of the Los Frailes caldera. *Mineralium Deposita*, 25 (Suppl.) 21-28.

Hernández Ortiz, F. 2002. Minas de alumbre de Rodalquilar en el obispado de Almería siglo XVI. *Tierra y Tecnología*, 24, 1-9.

Hernández Ortiz, F. 2008. La minería del oro de Rodalquilar durante el siglo XX: La estructura empresarial y su influencia en el éxito minero. *Boletín Geológico y Minero*, 119 (3), 343-360.

Martín-Vivaldi, J.L., Sierra, J. and Leal, G. 1971. Some aspects of the mineralization and wallrock alteration in the Rodalquilar goldfield, SE Spain. *Society of Mining Geology Japan, Special Issue*, 2, 145-152.

Rytuba, J.J., Arribas Jr., A., Cunningham, C.G., McKee, E.H., Podwysocki, M.H., Smith, J.G., Kelly, W.C. and Arribas, A. 1990. Mineralized and unmineralized calderas in Spain; Part II, evolution of the Rodalquilar caldera complex and associated gold-alunite deposits. *Mineralium Deposita*, 25 (Suppl.), 29-35.

APPENDIX

FIELD TRIP GUIDE TO THE RODALQUILAR DEPOSITS

INTRODUCTION

The morning stops (stops 1 through 4; Fig. 2) will be devoted to study the evolution of the Rodalquilar volcanic complex that culminated in the formation of the nested Lomilla caldera. The following stops, stops 5, 6 and 7, will concentrate on the location, nature, and genesis of the high-sulfidation type gold deposits and associated hydrothermally altered rocks. Place names used in the text are shown on the topographic base map of the 1:25,000-scale geological map of the Rodalquilar volcanic complex (Arribas, 1993). The last two stops of the day (stops 8, which is optional, and 9) focus on the secondary (supergene) processes and the resulting alunite deposits which were mined during the 1500s.

STOP 1. OVERVIEW OF THE OUTFLOW FACIES OF THE CINTO ASH-FLOW TUFF

Stop 1 is located on the paved highway from San Jose to Rodalquilar, about 700 m north of the intersection with the road to Los Escullos. The outflow facies of the Cinto ash-flow tuff comprises most of the plateau named La Rellana, which lies to the north and northwest. The Cinto ash-flow tuff on La Rellana consists of a sequence of ash-flow tuffs and interbedded volcaniclastic rocks and air fall tuffs. Six cooling units have been identified in the section of tuffs exposed just to the north of Cortijo El Carrizalejo (see Rytuba et al., 1990). The ash flows were erupted from the Rodalquilar caldera located about 4 km to the north. They dip gently and individual flow units can easily be traced along the south facing scarp of the plateau. North-south trending faults locally displace the tuffs, north of the town of La Isleta. The ash-flow tuffs erupted from lithic-rich to pumice-rich and the size of lithic fragments and pumice clasts increases toward the north, reflecting their source from vents in the Rodalquilar caldera. Locally, volcaniclastic sediment and air-fall tuff separate individual cooling units. East of Cortijo El Carrizalejo, the sequence of ash-flow tuffs was deposited on an irregular precaldera surface of andesite flows and flow breccias. In contrast, west of El Carrizalejo, the Cinto ash-flow tuff is underlain by an older light-colored outflow tuff erupted from the Los Frailes caldera, located 2 km south of stop 1. The northern margin of the Los Frailes caldera is marked by the line of domes protruding above the valley floor just south of the paved road, near the intersection with the Las Presillas Bajas road. The highest peaks on the skyline to the south are pyroxene andesite flows, the youngest volcanic units (8.5-7.5 Ma) within the Los Frailes caldera.

STOP 2. OVERVIEW OF THE RODALQUILAR CALDERA

Stop 2 is located along the paved highway from San Jose to Rodalquilar at the summit located 2.2 km south of the town of Rodalquilar. The Rodalquilar caldera is an oval collapse structure having a maximum diameter of 8 km in an east-west direction and a minimum diameter of 4 km in a north-south direction (Figs. 2 and 3). From the crest of the hill (elevation 149 m), a few 100 meters southeast of Cerro Los Guardas, the entire central part of the Rodalquilar caldera is easily seen. The morphology of the caldera is still well preserved despite its Miocene age. The southern caldera margin can be followed for a strike length of 5 km and is defined by the northern scarp of La Rellana. The outcrops at this view point consists of outflow facies of the Cinto ash-flow tuff that contain large pumice and lithic fragments. The tuff was deposited on precaldera andesite flows. The topographic wall of the caldera is exposed along the sea coast just to the east of Cerro de los Guardias, the hill about 1 km to the northeast. Along the sea coast unwelded Cinto ash-flow tuff is deposited on precaldera andesite flows. The southern structural margin of the caldera is covered by a series of rhyolite ring domes emplaced shortly after collapse of the caldera. The broad basin in which the town of Rodalquilar is located is the moat of the Rodalquilar caldera. Cerro Cinto, the high hill west of Rodalquilar, is the resurgent dome of the Rodalquilar caldera and is composed of a thick sequence of intracaldera Cinto ash-flow tuff and collapse breccias. These beds were domed upward by resurgence of the magma chamber just after caldera collapse. The northern structural margin of the caldera is well exposed and occurs just south of the range of hills that defines the northern skyline. The high hill just beyond the gold mine tailings is Cerro de la Hortichuela, a rhyolite ring dome emplaced along the northern structural margin of the caldera (Fig. 2, 3). To the east, younger pyroxene andesite flows and breccias and marine sediments cover the eastern part of the caldera.

STOP 3. NORTH WALL OF THE RODALQUILAR CALDERA AND INTRACALDERA CINTO ASH-FLOW TUFF AND COLLAPSE BRECCIAS

The north structural margin of the Rodalquilar caldera is well exposed for a distance of about 2 km just west of the town of Hortichuelas (Fig. 3A). The caldera margin is defined by a single, nearly vertical fault that separates precaldera domes, on the east side of the fault, from intracaldera Cinto ash-flow tuff and interbedded collapse breccia, on the west side of the fault (Fig. 2). The structural margin of the caldera is exposed over a vertical distance of 200 m and provides one of the few localities in the world that clearly exposes a caldera structural boundary. The caldera margin crosses the old paved road heading north from the town of Hortichuela about 1 km northwest of town. Looking north from this point, the caldera margin is clearly exposed just east of a ravine cut into the south flank of Cerro Gallinaza.

Over 200 m of intracaldera facies Cinto ash-flow tuff and collapse breccia are spectacularly exposed inside the caldera and can be easily viewed in road cuts along the paved road which climbs the south flank of Cerro Gallinaza. More than 30 individual ash-flow tuff and collapse breccia beds are present in this caldera-fill sequence. Each collapse breccia bed resulted from failure of the oversteepened caldera wall and landsliding of these caldera wall rocks into the caldera as the eruption of the Cinto tuff occurred. Beds of unwelded, Cinto ash-flow tuff are gray-white to light tan and consist of uncollapsed pumice in an ashy matrix. Compositionally, this facies of the Cinto ash-flow is a rhyolite which contains phenocrysts of quartz, biotite, and plagioclase. Lithic fragments of andesite and dacite from precaldera flows and domes comprise the dark angular clasts in the tuff. The collapse-breccia beds include a variety of precaldera rocks which formed the wall of caldera. They consist primarily of porphyritic dacite and associated vitrophyre from precaldera domes. The lithic fragments in the breccia generally range from 0.25 to 2 m in diameter but some breccia beds contain fragments up to 15 m in diameter. The matrix of the collapse breccia consists of uncollapsed gray-white to tan pumice and ash. The collapse breccia beds are thickest at the margin of the caldera and thin toward the central part of the caldera.

The thick sequence of intracaldera Cinto ash flow tuff extends into the central part of the Rodalquilar caldera (the area called Cerro del Cinto), and its attitude reflects the structural doming of the caldera. Near the caldera margin the beds dip inward toward the caldera at about 10 degrees; they are horizontal near the margin of the resurgent dome, and then dip radially outward from the caldera at up to 20 degrees in the central part of the resurgent dome. Structural doming of the central part of the caldera resulted in the formation of a circular, topographic basin (moat) adjacent to the caldera wall. The morphology of the moat is preserved in an area of low topographic relief south of Cerro Cinto.

Looking south from this stop near the top of Cerro Gallinaza, the ring dome emplaced along the north margin of the caldera (Cerro de la Hortichuela) is well exposed. In its central part, the Hortichuela dome consists of vertically flow-foliated porphyritic rhyolite, whereas in the northern and western margins it consists of massive flows that cover interbedded intracaldera Cinto ash-flow tuff and collapse breccia. A thick, strongly foliated, hornblende andesite flow caps the top of the intracaldera sequence of Cinto ash-flow tuff and collapse breccia on the top of Cerro Gallinaza and along the ridge extending southwest. The flow (9.0 ± 0.6 Ma) erupted within the moat of Rodalquilar caldera during the final phase of caldera volcanism.

STOP 4. RELATION OF LÁZARAS ASH-FLOW TUFF TO RHYOLITE RING DOMES ALONG THE SOUTH MARGIN OF THE RODALQUILAR CALDERA

Stop 4 is reached by the unpaved road heading west of Rodalquilar for 1. 7 km. An old unpaved road intersects the road, from the east, at this point. Proceed down this unused road for 0.3 km. Volcanic ring domes were emplaced after collapse of the Rodalquilar caldera along the southern structural boundary of the caldera for a distance of about 5 km and locally extended into the caldera. The domes consist of massive, flow foliated rhyolite with sparse quartz and plagioclase phenocrysts. They are typically mantled by a carapace of debris-avalanche deposits derived from the domes and have a diagnostic fracture pattern that developed during cooling of the domes. The fracture pattern strongly contrasts with other units in and outside the caldera, and is very well displayed on air photos. The original conical or domal shape of the domes is remarkably well preserved. The domes emplaced along the southern margin of the caldera extend northward into the caldera for a distance of about 1.5 km.

In the creek just south of the hill named Las Lázaras, the relationship between the Lázaras ash-flow tuff and the rhyolite ring domes is well exposed. Here the Lázaras ash-flow tuff rests on top of the rhyolite ring dome. This same relation is found everywhere in the Rodalquilar caldera and indicates that ring dome emplacement was complete before eruption of the Lázaras ash-flow tuff. The first outcrops in the creek consist of air fall and water laid tuffs deposited on the moat of the Rodalquilar caldera. Further down the road, more densely welded Lázaras ash-flow tuff contains large collapsed pumice clasts. About half way up the exposed section, the Lázaras ashflow becomes columnar jointed and more densely welded. Eruption of the Lázaras ash-flow tuff resulted in formation of the Lomilla caldera which is nested within the larger and older Rodalquilar caldera. The Lázaras ash-flow tuff filled the eastern and southern moat of the Rodalquilar caldera.

STOP 5. THE CINTO-TRANSACCIÓN AU DEPOSITS AND CROSS-SECTION OF THE MAIN ZONE OF ADVANCED ARGILLIC ALTERATION AT RODALQUILAR

The Cinto deposit was mined from 1943 to 1966 by the Spanish national company ADARO and between 1989 and 1992 by St. Joe Transacción, owned by Cluff Resources and Antofagasta Holdings. The visit to the Cinto deposits will concentrate on open pit no. 1 and adjacent mine workings. Stop 7 also includes a NW -SE cross-section through the core of altered rocks along the 270-m bench road of Cerro del Cinto. This cross-section provides a particularly good traverse of the zones of altered rock because much of the alteration occurs within a lithologically homogeneous rhyolitic dome. The mineralogy based on X-ray analysis of samples collected at ~20 m intervals along this traverse (Fig. 5). illustrates the close relationship existing between the zones of vuggy silica, advanced argillic alteration, and the principal Au vein zones.

The large (>0.5 km2) area of advanced argillically altered rocks in the Cinto center surrounds the cores of vuggy silica and encloses most of the Au mining works at Rodalquilar. Here, advanced argillically altered rocks continue to depths of over 300 m and grade with increasing depth into intermediate argillic and sericitic alteration zones. Vuggy silica occurs closer to the surface and to the conduits of hydrothermal fluids. The groundmass in vuggy silica is strongly silicified and the porosity of the rock is due to the dissolution of pumice and lithic fragments as well as igneous phenocrysts other than quartz. This indicates extreme leaching by acid hydrothermal solutions (pH<2), conditions that were attained when HCl and S02 from a magmatic vapor plume reacted with meteoric or even magmatic water (the O and H isotope composition of Stage 1 alunite indicates a dominant magmatic component). Within the advanced argillic zone, and particularly at the outcrop scale, two sub-types of alteration may be distinguished. A zone of quartz+alunite±kaolinite is found closer to the zone of vuggy silica and grades outwards into a zone of quartz+kaolinite. The two zones have very irregular shapes and distributions, but the quartz+kaolinite zone is larger and grades into the surrounding argillic zone. Other than quartz, altered rocks in the advanced argillic zone contain variable amounts of alunite (Stage 1 alunite), kaolinite/dickite, pyrite and pyrophyllite. Accessory, but characteristic minerals include diaspore, zunyite $[Al_3Si0_2(OH,F)_{18}Cl]$, rutile or anatase, svanbergite, woodhousite $[(Ca,Sr)Al_3(P0_4)(S0_4)(OH)_6]$, lanthanum florencite $[(Ce,La)Al_3(P0_4(OH)_6]$, and rare covellite, enargite, and bornite.

STOP 6. OVERVIEW OF THE RODALQUILAR AND LOMILLA CALDERAS AND ZONES OF HYDROTHERMAL ALTERATION

Stop 6 is located on the top of the eastern wall of the Lomilla caldera. To reach this stop take the unpaved road that climbs to open-pit 3 of the Transacción mine, turn right before the open-pit and follow the road to a location on the crest of the hill marked by an old pluviometer. The view from stop 6 provides a superb summary of the geological evolution of the Rodalquilar and Lomilla calderas and of the timing, extent, and location of the large hydrothermal systems that formed the gold deposits within the caldera.

The Lomilla caldera is a well preserved, oval collapse structure with a maximum diameter of 2 km. The Lomilla caldera is nested within the central part of the larger Rodalquilar caldera in the area that was part of the Rodalquilar caldera resurgent dome. The arcuate scarp developed along the west face of the hill named Cerro Cinto forms the eastern topographic wall of the Lomilla caldera The vertical relief along the caldera wall is over 100 m. The western topographic wall of the caldera is less well preserved and defined by a scarp with a vertical relief of about 70 m developed along the east facing side of Cerro de la Cruz. The Lomilla caldera is filled with a thick sequence of interbedded collapse breccia and Lázaras ash-flow tuff. Drilling in the small hills (Lomilla de Las Palas) within the central part of the Lomilla caldera, encountered about 300 m of intracaldera fill deposited on the Cinto ash-flow tuff. Total collapse associated with the formation of the Lomilla caldera is estimated to be about 0.5 km.

Looking east from the crest of the hill (elevation 308 m), Cerro Gallinaza marks the north structural margin of the Rodalquilar caldera. The high hill to the right of Cerro Gallinaza is Cerro de la Hortichuela, a ring dome emplaced along the northern margin of the caldera. To the southeast, in the distance, the Cerro de Los Guardas marks the southeastern margin of the caldera and, in front of it, a rhyolitic dome is surrounded by the Lázaras ash-flow tuff (Stop 4). In the foreground, the topographic basin of the Rodalquilar caldera is filled by up to 80 m of Lázaras ash-flow tuff that is overlain by moat sediments and a silicified pyroclastic unit that is easily seen in the crest of a hill situated behind the alunite quarry. This silicification is stratigraphically controlled and is younger than the hydrothermal systems. The next episode of volcanic activity is marked by hornblende andesite flows and intrusions that appear unaltered on the low hills behind Rodalquilar to the southeast. However, a few of the hornblende andesite flows are altered and mineralized (e.g., Cinto open-pit no. 3) indicating that mineralization occurred during the early phase of andesitic volcanism but ended before the last flows were emplaced. The youngest volcanic rocks in the Rodalquilar area, unaltered pyroxene andesite flows and breccias, form the high hills in the far distance to the right of El Playazo beach. Small, scattered, plugs of unaltered pyroxene andesite are located in the moat of the caldera crosscutting zones of intense advanced argillic alteration and one of these will be visited in stop 8. The sea invaded then the caldera, and fossiliferous Tortonian and Messinian sediments covered the topography resulting in a better preservation of the surficial geologic features. Remnants of these sediments form Cerro El Romeral and Cerro La Molata.

Late stage resurgence within the Rodalquilar caldera occurred near the final stage of emplacement of the hornblende andesitic magma. Evidence for the late stage resurgence is the tilting and doming of the entire caldera-fill sequence, including Lázaras ash-flow tuff, caldera-fill sediments, pyroclastic flow deposits, and hornblende andesite flows. The area of greatest late stage doming was in the south central part of the Rodalquilar caldera near the southern end of Cerro Cinto. North-south trending faults and fractures that cut the caldera likely developed during this resurgence. This late stage resurgence was important in opening arcuate and radial faults and fractures in the caldera wall. These fractures were used as fluid pathways by large hydrothermal systems which subsequently developed in the caldera and are host to the Au deposits. The eastern wall of the Lomilla caldera is also the core of hydrothermally altered rocks and the locus of a gravimetric and aeromagnetic high in the Rodalquilar area.

With respect to the Au mineralization, the chalcedony veins, the principal ore in open-pits no. 1 and 2, represent a very irregular type mineralization, both in form and grade, but they are the most representative of the Rodalquilar deposits. The principal type of veins occupy narrow, irregularly intersecting fractures that often grade into small breccia bodies. The veins form steeply-deeping, irregular silicified masses that may vary in width from a few cm (essentially a fissure in the rock) to more than 1 m. Typically, they are less than 40 cm wide. The interior of the veins consists of brecciated host rock and massive to banded chalcedony, which is the main Au ore. The wall of the veins is generally volcanic rock altered to vuggy silica which indicates that Au mineralization occurred after hypogene acid-sulfate alteration, as the magmatic-hydrothermal systems evolved. The chalcedony occurs in three general habits: (1) dark gray to black chalcedony, commonly with irregular banding, (2) black chalcedonic replacement of host rock; and, (3) horizontally layered, often massive, white to light gray chalcedony deposited after the first two varieties. Banding in black chalcedony is enhanced by weathering of pyrite to form jarosite and hematite. Morphologic features observed in the banded chalcedony, such as slump structures and thicker silica deposits on the bottom than on the sides of the cavities, suggest initial silica precipitation as amorphous silica which later recrystallized to cristobalite or opal-CT and finally to chalcedony or quartz.

STOP 7. ALUNITE STAGE 2 ALTERATION AND 340 VEIN

Stop 7 is located on the unpaved road which descends to Rodalquilar, between the 340 vein and the Cortijo La Pedrera. The 340 vein is on the left side of the road and is easily recognizable by the green-blue mine dumps. The 340 vein is inaccessible but it is the best example at Rodalquilar of high-grade hydro-thermal breccias. The vein was discovered in the early 1960s and produced almost 1 ton of Au in just a few years of production (overall grade was 43 g/t Au but significant intervals had grades higher than 500 g/t Au; Martín-Vivaldi et al., 1971). The 340 vein encloses a breccia that consists of angular lithic fragments (<1 to > 10 cm across) of vuggy silica, advanced argillically altered rock and rare chalcedonic quartz enclosed in a matrix of white chalcedony. The primary mineralization is observed in 1-5 mm thick rims of dark chalcedony around some lithic fragments that contain fine-grained calaverite, native Te, and minor pyrite. However, these minerals are rarely preserved, instead being replaced by an oxidized assemblage of native Au, tellurite (TeO_2), goethite, rodalquilarite [$H_3Fe_2(TeO_3)_4Cl$], and a compound of Fe and Te, tentatively identified as blakeite (ferric tellurite). Other minerals present in the 340 vein are pyrite, enargite, cassiterite, bornite, naumannite (Ag_2Se) and a Cu selenide. Wood-tin is late-stage and occurs preferentially in the silicified selvages of the vein as brown crusts and open space fillings with chalcedonic quartz. The primary Au mineralization in the 340 vein is interpreted to be related to a period immediately following the eruption of the hydrothermal breccia which probably resulted from self-sealing of fractures by deposition of hydrothermal silica, generation of high-fluid pressures, and eventual rupture and rapid flashing of steam that fractures the rock. Hydrothermal brecciation led to the ideal conditions for deposition of silica minerals and Au (i.e., temperature and pressure decrease, loss of volatiles, and changes in pH).

In addition to the hydrothermal activity responsible for Stage 1 alunite, a second period of acid-sulfate alteration has been documented at Rodalquilar which is characterized by Stage 2 alunite (Arribas et al., 1995). Stage 2 alunite forms thin, cryptocrystalline veinlets that cut any previous alteration type. These porcellaneous veinlets are found scattered across the Rodalquilar and Lomilla calderas, and consist of very fine-grained (<5 mm) pseudocubic alunite, with minor chalcedonic quartz, kaolinite, jarosite, and hematite. Stage 2 alunite occurs chiefly within shallow, intensely altered and barren areas which surround the central core of advanced argillic alteration but are also superimposed upon it. The road cut next to Cortijo La Pedrera has excellent examples of this type of alteration, including abundant cross-cutting yellow alunite-jarosite veins. The white host-rocks are caldera-fill tuffs replaced by quartz, kaolinite, illite-montmorillonite, alunite, hematite, and jarosite. K-Ar ages for Stage 2 alunite are between 3 and 4 Ma and indicate an origin unrelated to the hydro-thermal event of Stage 1 alunite at about 10.4 Ma. This information, combined with evidence against a geothermal or magmatic-hydrothermal origin derived from the analysis of oxygen isotope ratios of the alunite OH group, all point towards a supergene origin for Stage 2 alunite.

STOP 8. ALTERED CALDERA-FILL ROCKS AND INTRUSION OF UNALTERED PYROXENE ANDESITE

Stop 8 is located on the moat of the Rodalquilar caldera, next to the eastern flank of the central resurgent dome. To reach it, take the small unpaved road that intersects the road to Rodalquilar about 300 m east of stop 7. This road is on the caldera fill which, in this area, consists of about 50-90 m of Lázaras ash-flow tuff and 15-30 m of lacustrine sediments and silicified volcaniclastic rocks. On the northwestern side of the road, the Lázaras ash-flow tuff was ponded against the resurgent dome that consists of Cinto intracaldera ash-flow tuff and interbedded breccias. Along the flank of the dome, the Cinto ash-flow tuff dips radially outward from the Lomilla caldera at 10-30 degrees. On the southeastern side of the road, the Lázaras ash-flow tuff was deposited against a rhyolite ring dome. The road crosses several areas of intensely altered rocks, containing abundant Stage 2 alunite, that are located concentrically around the resurgent dome.

Take the road to the left that follows the Barranco de La Felipa and continue until about 300 m before the end of the road. Along the way, there is a short road to the left that leads to the location of the DH-3 drill hole that was drilled by ADARO and provided an informative section through rocks of the eastern part of the

Rodalquilar caldera. The hole encountered 50 m of Lázaras ash-flow tuff and 330 m of Cinto ash-flow tuff before the precaldera andesites were reached at a depth of 250 m below sea level. This is in contrast with over 300 m of Lázaras ashflow tuff and 860 m of Cinto ash-flow tuff cut in drill holes in the Lomilla caldera.

To reach stop 8, climb the road along the Barranco de la Felipa towards the west to a narrow open-pit alunite mine located on the flank of the resurgent, dome. The sequence of lacustrine sedimentary rocks on top of the Lázaras ash-flow tuff is very well represented here. Local beds of tallus breccia derived from the resurgent dome are interbedded with the sediments. The eastern wall of the open pit exposes one of these breccias that contains large clasts of lacustrine sedimentary rocks up to 1.5 m in diameter. The matrix of the breccia is partly silicified. This silicification appears to be associated with the stage of stratigraphically-controlled silicification of the overlying lithic ash-flow tuff. The preservation of the central dome and the presence of the talus breccias in the moat of the caldera indicate that there was significant topographic relief within the Rodalquilar caldera. Stop 8 also allows observation of one of the small (some <250 m2) exposures of unaltered pyroxene andesite that crop out in the central part of the Rodalquilar caldera cutting through intensely altered and mineralized Cinto and Lázaras ash-flow tuffs. The presence of the unaltered pyroxene andesites places definite constraints on the timing of alteration and mineralization.

STOP 9. CASTILLO DE RODALQUILAR AND XVI CENTURY ALUM MINING WORKS

Mining in the Rodalquilar area dates to the Middle Ages, when secondary (supergene) alunite (Stage 2 alunite) veins were exploited for the production of alum. These open pits and cuts occur in two main areas (Los Tollos and La Felipa) and are genetically associated with a supergene overprint at ~3-4 Ma of the advanced argillically altered (at ~10.4 Ma) volcanic rocks. Alum mining started in Rodalquilar in the early 1500 following the discovery of similar deposits in other regions of the western Mediterranean (Tolfa in Italy, Mazarrón in SE Spain near Cartagena, among others). Alum was a valuable chemical in the Middle Age and was used principally in the textile industry as a fixing agent for dies and as a tanning agent to produce more supple leather and in the paper industry for the production of parchment.

Stop 8 included a visit to the La Felipa alunite vein and cut. Stop 9 provides an overview of the Los Tollos ancient alum mining area and the ruins of Castillo de la Ermita (also known as Castillo de Rodalquilar), which was built in the early 1500s to provide protection for the alum mines and, likely, as a processing facility (Hernández Ortiz, 2002, 2008). Interestingly, the Rodalquilar alum mines were owned by the Catholic Church, in a situation similar to that of the Tolfa mines in Italy, which were owned by the Pope. Mining of alum at Rodalquilar occurred intermittently during the XVI century and stopped completed by the 1592 alum shale deposits were discovered in other parts of Europe.

J. E. Ortiz, O. Puche, I. Rábano and L. F. Mazadiego (eds.) *History of Research in Mineral Resources*. Cuadernos del Museo Geominero, 13.
Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-856-6

THE CAMPO DE CALATRAVA VOLCANIC FIELD: GEOLOGY AND RESOURCES

Pablo L. Higueras Higueras and José Luis Gallardo Millán

Instituto de Geología Aplicada, Universidad de Castilla-La Mancha, Pl. Manuel Meca 1, 13400 Almadén (Ciudad Real), Spain.
pablo.higueras@uclm.es

Abstract. The volcanic region of Campo de Calatrava, located in South-Central Spain, and in particular in the Ciudad Real Province (Castilla-La Mancha region) is one of the three most important areas with recent volcanic activity in the Iberian Peninsula, together with those of Olot (Gerona, in Catalonia) and Cabo de Gata (Almeria, in Andalucía). In this work we describe succinctly the characteristics of this volcanism, as well as the related iron and manganese (plus minor cobalt) oxides mineralizations. Finally, an also brief description of the legal measures implemented to protect the local volcanic buildings is included.

1. INTRODUCTION

The volcanic region of Campo de Calatrava (Fig. 1) is one of the three most important areas with recent volcanic activity in the Iberian Peninsula, together with those of Olot (Gerona, in Catalonia) and Cabo de Gata (Almeria, in Andalucía). Eruptive activity took place between 0.7 and 8.7 million years ago, ie during Pliocene and Quaternary. It is therefore a rather recent activity, which has allowed the volcanic edifices largely retain their original morphology, and their products have been relatively well preserved until today, despite modern mining activity to exploit the volcanic materials as aggregates and for concrete (puzzolan) production.

The volcanic region has a total area of about 5000 km^2, and includes some 240 different volcanic edifices. Some of the main towns of the Ciudad Real province are included within the area: Ciudad Real, Almagro, Daimiel and Bolaños. Puertollano is placed close to the extreme South, while the volcanic edifices located closest to Almadén are those of La Bienvenida and Cabezarados.

2. MORPHOLOGICAL AND GENETIC ASPECTS

The geomorphology of the Campo de Calatrava region is conditioned by the existence of a series of Pliocene-Quaternary basins, which are bounded by sierras constituted by Paleozoic quartzite rocks. Within the basins the landscape is very smooth, and it is only modified by the presence of the volcanic edifices, which produce very striking features and morphologies (Fig. 2), which traduces in also characteristic place names, so that these volcanic edifices are named as "Negrizal de las Casas","Cabeza Parda","Cerro Moreno", etc. Also to note is the presence of *"lagunas"* (small lakes, or wetlands), corresponding to the sites of hydromagmatic activity (see below).

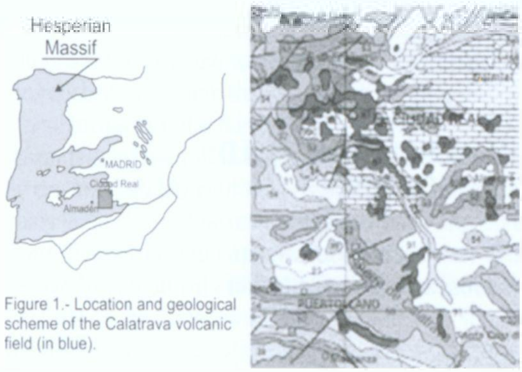


Figure 1. Location and geological scheme of the Calatrava Volcanic field (in blue).

Figure 2. Castillejo de La Bienvenida, one of the characteristic volcanic edifices dominating the almost plain landscape of the area.

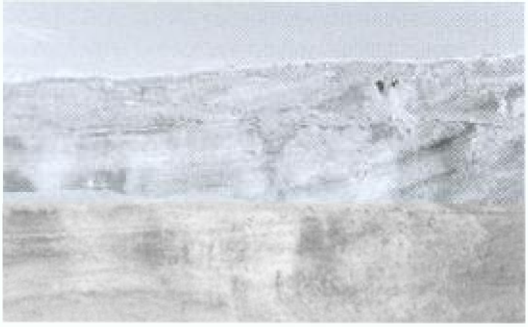


Figure 3. La Yezosa volcanic edifice, affected by quarry activity.

The conservation of individual volcanic edifices depends on several factors:

—Eruption age (the latest are better preserved).
—Original edifice morphology.
—Volume of erupted materials.
—Nature of eruption products.
—Geological location (basins or quartzite reliefs).
—Modern mining activity.

This means that in each case it may be more or less complicated the identification of the volcanic nature of the edifice concerned.

Eruptive mechanisms responsible for these morphologies have been essentially of two types: Strombolian and Hydromagmatic. There are no edifices that could correspond to Hawaiian-type eruptions, but there are lava flows of a certain volume issued by Strombolian volcanoes.

Strombolian volcanism originated small conical volcanoes, now downgraded to rounded hills, with tapered hemispherical forms, depending on the degree of erosion. Their diameters range from 100 m to 2 km, and their heights, from 20 to 120 m. Crater-like depressions can occasionally be identified. Lava flows are occasionally emitted from these volcanoes, which can lead to achieving the 6-7 km long. Some of the best examples of this type of volcano are the La Yezosa in Almagro (Fig. 3), and Cerro Gordo in Valenzuela de Calatrava (Fig. 4).

Hydromagmatic volcanism is the most common in the region and gives rise to some very distinctive volcanic edifices, but often difficult to identify as such in the field: the so called "maars", depressions surrounded by a ring of pyroclastic products, which can reach diameters of 1-1,5 km. Most of these maars are occupied by wetlands. One of the most representative examples might be the small lakes or wetlands of Caracuel and La Posadilla (Fig. 5), or Hoya del Mortero depression (Fig. 6) in Poblete.

3. PETROGRAPHY

The volcanic rocks emitted by these volcanoes co-

Figure 4. Cerro Gordo, with a lower layer of porphyritic materials and a top layer of pyroclasts.

Figure 5. Partial view of the *Laguna de Fuentillejo*, also known as La Posadilla, maar-type wetlands declared as Natural Heritage by Act 207/1999.

Figure 6. Hoya del Mortero, a deep endorreic basin also of mar typology.

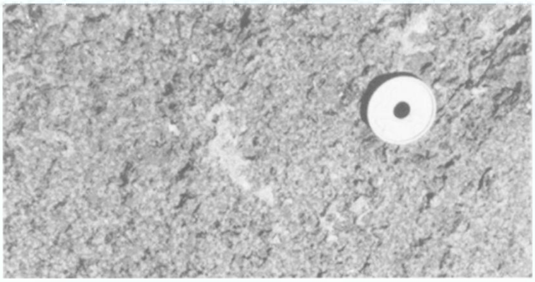


Figure 7. Macroscopic aspect of a local basalt sample.

rrespond to basalts in broad sense; they can be differentiated a number of varieties, both i) compositional: olivine melilitites, limburgites, olivine nephelinites, basanites and olivine leucitites, and ii) textural: massive porphyritic rocks, scoriaceous pyroclastics (tepha) and hydromagmatic deposits, constituted by heterometric mélanges of host rocks and volcanic fragments.

Massive porphyritic varieties have porphyritic texture, and consist of phenocrysts of olivine or olivine and pyroxene in a microcrystalline to glassy matrix formed by crystallites of augite, iron and titanium oxides (magnetite-ilmenite) and olivine. They can also contain plagioclase, feldspathoids, melilite and glass, in varying proportions, allowing finer petrographic classification as above indicated. Figures 7 and 8 show the macroscopic aspect of two of these varieties.

In regard to their applications, massive porphyritic varieties have been used until recently in obtaining cobblestones for paving streets. Its main current application is to obtain crushing aggregates, and especially for obtaining ballast for high-speed train (AVE) crossing the volcanic area. One of the main existing quarries on such materials is that of Morrón de Villamayor. They also have utility as building stones.

Tepha-type varieties are very vacuolar, of "pumice" type, and they form masses constituted by rocks fragments of widely varying sizes: from clusters of very fine grained material, (ash) to accumulations of large blocks, passing through very heterometric accumulations of medium-sized fragments centi-to decimeter (lapilli), with occasional presence of much larger fragments (bombs). Figures 10 to 13 show illustrations of some examples from these rocks types.

These materials are mined in several quarries in the region to obtain pozzolan concrete (Figure 14), which is its main industrial application. It should be noted, moreover, that have also been used as building stone, in monuments such as the Calatrava La Nueva Castle, and the Visigothic shrine of Virgen de Zuqueca in Oreto (Granátula de Calatrava).

Hydromagmatic deposits are usually well-stratified,

Figure 8. Macroscopic aspect of an olivine leucitite, from Morrón de Villamayor. It constitutes the only outcrop of this type of rocks in Europe.

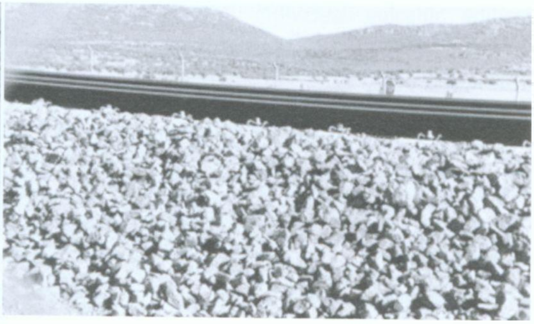


Figure 9. Basaltic ballast at the AVE railway.

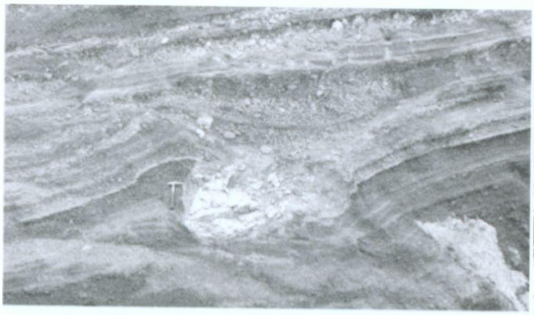


Figure 10. "Bomb sag" structure in pyroclasts from the Cerro Gordo volcano.

Figure 11. Lapilli pyroclasts, La Atalaya volcano (Ballesteros de Calatrava).

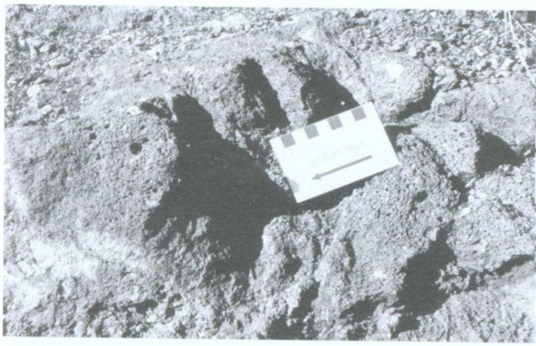


Figure 12. Scoriaceous aspect of pyroclasts products, La Atalaya volcano (Ballesteros de Calatrava).

Figure 13. Heterometric pyroclast material with large bomb. Quarry at Almodovar del campo volcano.

Figure 14. Puzzolan quarry. Ballesteros de Calatrava.

alternatively with planar or cross-stratified facies. In addition, they contain large bombs, usually constituted by non-volcanic material (quartzite, basically).

They correspond to unconsolidated heterometric lithic and crystal-lithic tuffs, consisting largely of fragments of Paleozoic rocks (quartzite, shale), with minor co-genetic volcanic components (basaltic fragments, crystals of olivine, pyroxene, etc.).

These rocks do not have industrial utility, rather than to obtain low quality classified aggregates.

4. GEOCHEMISTRY

From the geochemical point of view, the volcanic rocks from the Campo de Calatrava field correspond to an intraplate alkaline magmatism, generated from low rates of upper mantle partial melting. Magmas would be primary liquids, as indicated by high contents of Ni and the high value of #Mg parameter (MgO/MgO + FeO). Table 1 shows the average chemical composition and CIPW Norm calculated from the porphyritic varieties.

These geochemical characteristics, as well as data from the study of its evolution in time and space, allow a genetic interpretation related to the existence of a hot spot associated with a process of cortical lifting and possibly of aborted rifting for the magmatic activity present at the Campo de Calatrava volcanic field.

5. RELATED ORE DEPOSITS

Associated with this magmatism there are a number of minor mineral deposits, usually with low tonnage, but constituting a worldwide singularity. They correspond to Fe and Mn oxides, the latter with the added interest of showing relatively high Co content, and have been the subject of prospection in the 90's, aimed to identify larger deposits with these high Co contents.

The mineralizations have been characterized by Crespo et al. (1995) as of exhalative-sedimentary origin, appearing in the form of stratabound lenses within the Pliocene and Quaternary sequences, forming lenticular masses of up to several meters thickness and up to several hundred meters of lateral extent. Its origin seems to be related to other characteristics and much more common events of the area: the so called "hervideros" (boilers) and "agua agria" (sour water) springs, the best known of which could be the *"Fuente Agria"* in Puertollano. The genetic link would be that both mineralization and springs would be posthumous manifestations of hydrothermal activity linked to this magmatic activity.

Following Crespo et al. (1995), two major types of mineralizations can be differentiated in the area (Fig. 15):

— Proximal mineralizations, with respect to hydrothermal sources. Two subtypes can be stablished:

Fe-Mn oxides crusts.

Layers of "*canutillos*" (small spliffs) of Mn-(Co) oxides.

	Basalts	**Basanites**	**Olivine nefelinites**	**Olivine melilitites**	**Olivine leucitites**
SiO_2	44.32	43.01	40.14	37.29	44.40
Al_2O_3	12.06	11.94	11.67	10.44	10.93
Fe_2O_3	4.88	5.54	5.50	5.58	5.36
FeO	6.37	5.85	5.92	6.00	3.98
MgO	10.33	10.74	11.86	13.25	11.79
CaO	11.43	11.87	13.44	15.37	12.33
Na_2O	2.63	3.26	3.23	2.87	2.42
K_2O	1.18	1.08	1.02	1.37	3.73
MnO	0.16	0.18	0.18	0.21	0.16
TiO_2	3.04	3.09	3.35	3.06	2.27
P_2O_5	0.73	0.78	1.02	1.34	1.14
H_2O	2.45	2.21	2.49	2.49	1.52
Total	99.58	99.55	99.82	99.27	100.03
Ba	737	752	826	831	1154
Ce	77	95	111	137	133
Co	45	43	47	46	56
Cr	416	401	472	492	924
La	66	67	80	96	80
Ni	205	183	212	235	213
Rb	37	39	38	34	257
Sr	918	870	1047	1583	1057
Y	27	26	29	34	8
Zr	247	261	278	292	396
CIPW Norm					
Or	7.0	6.4	3.2	--	6.6
Ab	17.1	11.5	2.1	--	--
An	17.6	14.8	713.5	11.6	5.1
Lc	--	--	4.5	6.3	9.8
Ne	3.1	8.8	13.4	13.2	10.3
Di	26.2	29.9	35.7	25.1	31.0
Ol	11.7	10.1	11.5	16.77	22.3
Ln	--	--	--	6.8	--

Table 1. Chemical composition and calculated CIPW Norm for prophiritic rocks from the Campos de Calatrava volcanic field.

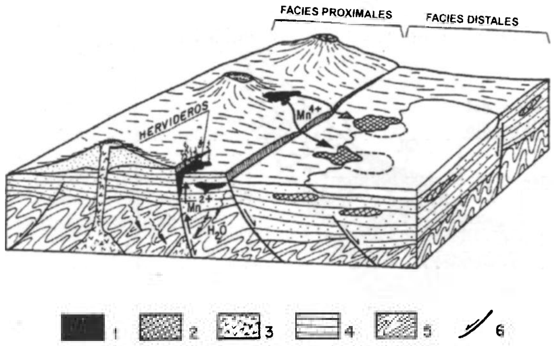


Figure 15. Geologic scheme of the Calatrava volcanic field Fe-Mn-(Co) deposits. 1: Proximal deposits. 2: Distal deposits. 3: Volcanic rocks. 4: Pliocene and quaternary detritic sequence. 5: Hercynian basement. 6: Fault.Photo 14.- Mn nodules (black) covered by an iron oxides crust (reddish). La Zarza mine.

Figure 16. Mn nodules (black) covered by an iron oxides crust (reddish). La Zarza mine.

—Distal mineralizations, with respect to hydrothermal sources: pisolithic layers with Mn-(Co) oxides.

Ore mineralogy includes complex manganese oxides and hydroxides: cryptomelane (KMn_8O_{16}) and lithiophorite ($(Al, Li)MnO_2(OH)_2$) are the main ores, and they appear in the form of earthy micro-or cryptocrystalline aggregates.

The Fe-Mn oxides crusts are lenticular formations of a few meters thickness and several hundred square meters in extension, generally associated with the "*agua agria*" springs, and are constituted by nodules of Co-rich Mn oxides covered with a crust of iron oxides and hydroxides some 1-1,5 cm. thick (Fig. 16). The mine of La Zarza, located some 2 km SSW from Pozuelo de Calatrava, is one of the most representative mineralization of this typology.

"Canutillos" layers are accumulations of Co-rich Mn oxides replacing vegetal structures, constituting which appear to form levels up to 2-3 m. thickness between alluvial materials. Mine Chorrillo, located in the vicinity of the La Zarza, is one of the best examples of this type of mineralization (Figs. 17 and 18).

Pisolithic layers with Mn oxide correspond to mineralizations that have suffered some transport for the hydrothermal sources. They consist of lenticular concentrations of Mn oxides and hydroxides pisolithic structures, centimetric in diameter. Los Ardales mineralization can be considered representative of this typology.

6. LEGAL PROTECTION

As stated in the preamble of the Spanish Law 42/2007 of Natural Heritage and Biodiversity: "In today's society has significantly increased concern with issues relating to the conservation of our natural heritage and biodiversity..." "... and degradation of natural areas of interest has become a serious concern for citizens, claiming their right to a quality environment adequate for their health and welfare". This law has established that public autho-

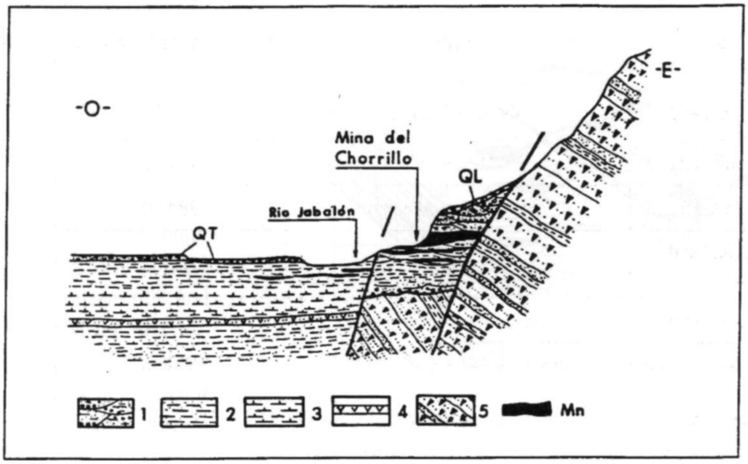


Figure 17. Geologic scheme of El Chorrillo mine. 1-4: Plio-Quaternary sediments. 5: Hercynian basement. Mn: *"Capas de canutillos"*.

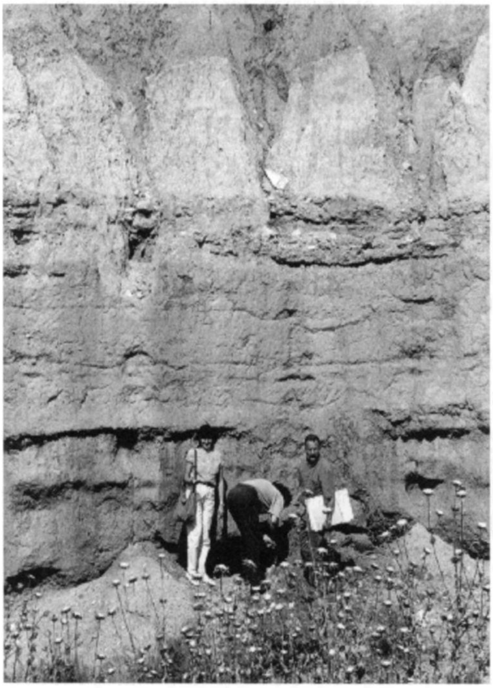


Figure 18. El Chorrillo mine. The dark level, coinciding with the person's highness, corresponds to the orebody thickness.

rities must be equipped with tools to know the state of conservation of Spanish natural heritage and biodiversity and the causes that determine their changes.

On the other hand, in the Region of Castilla-La Mancha has been considered, among other objectives for the development of the Law 9/1999 of 26 May of Nature Conservation: "to establish a protection framework, today inexistent, for certain geological and geomorphological features especially valuable".

This Law let to establish as Natural Monuments geological formations that after typology, development and extension, may be considered be representative of the geomorphologic domain where they are located. This has been the approach followed to estimate the protection needs of the recent volcanic manifestations of Campo de Calatrava as geological and geomorphologic features, and it is expressed as: "Because they can be considered as geological or geomorphologic features of special interest, either because they represent unique geomorphologic processes, ... characterize remarkable landscapes or possess special interest from the scientific or educational points of view".

As a result, and up to date, the Regional Government of Castilla-La Mancha has declared as Natural Monuments the volcanoes that are listed in Table 2.

Area Name	Location	Total declared area (ha)	Declaration date
Michos volcanic wetland	Abenojar, Luciana	218.00	5/10/1999
La Alberquilla volcanic wetland	Mestanza	111.00	5/10/1999
Hoya de Cervera Maar	Aldea del Rey, Almagro	284.00	5/10/1999
La Posadilla wetland and volcano	Alcolea de Cva.	296.00	5/10/1999
Los Castillejos de la Bienvenida	Almodóvar del Campo	197.00	5/10/1999
Peñarroya wetland and volcano	Alcolea de Cva. Corral de Cva.	544.00	5/12/2000
Hoya del Mortero Maar	Ciudad Real	124.00	5/12/2000
Cerro de los Santos volcano	Porzuna	120.00	27/09/2001
Calatrava volcanic massifs	Aldea del Rey, Almagro, Argamasilla de Cva., Ballesteros de Cva., Pozuelo de Cva.	3,763.00	24/06/2008
Piedrabuena volcano	Piedrabuena	480.30	31/03/2009

Table 2. List of volcanoes declared as Natural Monuments.

REFERENCES

Alberdi, M. T., Jiménez, E., Mazo, A. V., Morales, J., Sese, C. and Soria, D. 1984. Paleontología y Bioestratigrafía de los yacimientos Villafranquienses de las Higueruelas y Valverde de Calatrava II (Campo de Calatrava, Ciudad Real). *Actas de la 1ª Reunión de Estudios Regionales de Castilla-La Mancha,* 3, 255-277.

Ancochea, E. 1982. *Evolución espacial y temporal del vulcanismo reciente de España Central.* Ph.D. Thesis, Univ. Complutense, Madrid. Colección Tesis Doctorales, 203/83, 675 pp.

Ancochea, E. 1997. La región volcánica central española. In: Higueras, P. and Sánchez, C. (eds.), *XVII Reunión Científica de la SEM. Itinerarios Geológicos.* Universidad Castilla La Mancha, 27-53.

Ancochea, E. and Ibarrola, E. 1982. Caracterización geoquímica del vulcanismo de la región volcánica central española. *Boletín de la Real Sociedad Española de Historia Natural (Geología),* 80, 57-88.

Cebriá, J.M. 1992. *Geoquímica de rocas basálticas y leucíticas de la región volcánica de Campo de Calatrava, España.* Ph.D. Thesis, Universidad Complutense, Madrid, 324 pp.

Crespo, A. 1992. *Geología, mineralogía y génesis de los yacimientos de manganeso cobaltífero del Campo de Calatrava (Ciudad Real).* Ph.D. Thesis, Universidad Complutense, Madrid. 389 pp.

Crespo, A. and Lunar, R. 1997. Yacimientos de manganeso cobaltífero del Campo de Calatrava (Ciudad Real). In: Higueras, P. and Sánchez, C. (eds.), *XVII Reunión Científica de la SEM. Itinerarios Geológicos.* Universidad Castilla La Mancha, 55-88.

Crespo, A., Lunar, R., Oyarzun, R. and Doblas, M. 1995. Unusual case of hot springs-related Co-rich Mn mineralization in Central Spain: The Pliocene Calatrava deposits. *Economic Geology,* 90, 433-437.

Gallardo Millán, J.L., Ancochea, E. and Pérez-González, A. 2002. Secuencia magneto-estratigráfica y edad de los materiales volcánicos y sedimentarios de Poblete (Ciudad Real). *Geogaceta,* 32, 35-38.

Gallardo Millán, J.L. 2004. *Evolución geodinámica de las cuencas neógenas del Campo de Calatrava (Ciudad Real) y su relación con el volcanismo reciente.* Ph.D. Thesis, Universidad Complutense de Madrid, 322 pp.

González Cárdenas, E. 2010. *Aspectos geomorfológicos del volcanismo hidromágmatico del Campo de Calatrava, Ciudad Real,* 2/11/2010, http://www.uclm.es/ceclm/humedales/volca.htm

Hernández Pacheco, F. 1932. Estudio de la región volcánica central de España. *Memorias de la Academia de Ciencias Exactas, Físicas y Naturales,* 3, 235 pp.

Higueras, P. 2010. Volcanismo del Campo de Calatrava, 2/11/2010, http://www.uclm.es/users/higueras/Tema/Campos/Campos.htm

López Ruiz, J., Cebriá, J.M., Doblas, M., Oyarzun R., Hoyos, M. and Martín, C. 1993. Cenozoic intra-plate volcanism related to extensional tectonics at Calatrava, central Iberia. *Journal of the Geological Society of London,* 150, 915-922.

Martín-Serrano, A., Vegas, J., García-Cortés, A., Galán, L., Gallardo-Millán, J.L., Martín-Alfageme, S., Rubio, F.M., Ibarra, P.I., Granda, A., Pérez González, A. and García-Lobón, J.L. 2009. Morphotectonic setting of maar lakes in the Campo de Calatrava Volcanic Field (Central Spain, SW Europe). *Sedimentary Geology,* 222 (1-2), 52-63.

Molina, E., Pérez-González, A. and Aguirre, E. 1972. Observaciones geológicas en el Campo de Calatrava. *Estudios Geológicos,* 28, 3-11.

Portero, J.M., Ramírez, J.I., Ancochea, E. and Pérez González, A. 1984. *Mapa Geológico Nacional a escala 1:50.000. Hoja 974 (Ciudad Real).* Instituto Geológico y Minero de España, Madrid, 101 pp.

Rincón, P.J. 1999. *Análisis de la deformación incidente durante el periodo neotectónico en el antepaís bético (España central): Implicaciones morfoestructurales y origen del volcanismo reciente del Campo de Calatrava (Contrastación con otros entornos ígneos).* Ph.D. Thesis, Univ. Complutense de Madrid, 624 pp.

Ramírez, J.I., Ancochea, E. and Pérez González, A. 1984. *Mapa Geológico Nacional a escala 1:50.000, Hoja 975 (Almagro).* Instituto Geológico y Minero de España, Madrid, 72 pp.

Vegas, J., Galán, L., Pérez-González, A. and García-Cortés, A. 2004. El archivo lacustre del maar de Fuentillejo (Campo de Calatrava). Primeros protocolos científicos y estrategia de trabajo para el estudio paleoclimático del Cuaternario en el centro de España. *Boletín Geológico y Minero,* 115 (4), 641-650.

Authors' index

ISBN: 978-84-7840-856-6
9 788478 408566

MINISTERIO
DE CIENCIA
E INNOVACIÓN

Instituto Geológico
y Minero de España